Research Technical Completion Report
Project A-054-IDA
October 1976 - December 1977
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AQUACULTURE TECHNIQUES:
WATER USE AND DISCHARGE QUALITY

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Submitted to

Office of Water Research and Technology
United States Department of the Interior
Washington, D.C. 20240

April 1978

This project was supported primarily with funds provided by the Office of Water Research and Technology as authorized under the Water Resources Research Act of 1964, as ammended.

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Preface

This report is the technical completion report of a 15-month study entitled "Aquaculture Techniques: Water Use and Discharge Quality." The supporting agency was the Office of Water Research and Technology, Department of the Interior. The project was administered through the Idaho Water Resources Research Institute, University of Idaho.

In writing this report, we have attempted to present our findings and conclusions from a practical standpoint. It is our hope that fish culturists in both the public and the private sectors of aquaculture will find some of the concepts and methods described herein useful.

The collaborative efforts of the Idaho Department of Fish and Game are gratefully appreciated - especially those of the personnel at the Rapid River Salmon Hatchery and the Hagerman Trout Hatchery.

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I. INTRODUCTION

Abatement or at least reduction of pollutants in ground waters and streams is currently a national priority. In this regard, the Environmental Protection Agency in 1974 issued a "Development Document for Proposed Effluent Limitations Guidelines and Performance Standards for Fish Hatcheries and Farms." The final regulations have not been promulgated, but the issuance of permits based upon the proposed guidelines has been in progress for the past year or two.

Although the initial discharge limits in effect until June 30, 1977 for ammonia-nitrogen and solids (both suspended and settleable) were not too restrictive, the limits proposed for the period beginning 1 July 1977 are quite restrictive and will require extensive modification of current fish culture practices at most fish hatcheries and farms in Idaho and elsewhere in the nation. The proposed limits were derived largely from data gathered empirically and are, in the opinions of many, rather unrealistic. Furthermore, current fish culture methodology is not adequate to predict the time at which the limits will be exceeded in a given fish culture situation. In other words, an individual will not know he has exceeded the permitted discharge limitations until he has done so.

Idaho currently ranks third behind Washington and Oregon, in that order, in numbers of existing hatchery facilities. However, in terms of pounds of fish produced, Idaho leads the nation in trout and salmon production. The commercial food fish industry in Idaho produces 15 to 20 million lbs of rainbow trout and channel catfish annually in 69 currently licensed facilities. This is approximately 90% of the nation's commercial processed trout production. The Idaho Department of Fish and Game currently operates 17 hatcheries throughout the state. In FY-1974 the Department released 9.3 million spring chinook salmon, 0.3 million summer chinook salmon, 6.7 million steelhead and 5.2

million rainbow trout. During the same period the three U.S. Fish and Wildlife Service hatcheries in Idaho released 1.8 million steelhead, 3.0 million kokanee, 1.5 million rainbow trout and 0.8 million spring and summer chinook salmon.

The majority of the commercial fish farms (46 out of 69), one National Fish Hatchery, and three Idaho Department of Fish and Game hatcheries lie along a 25-mile stretch of the Snake River extending from Twin Falls downstream to Hagerman (Fig. 1). The current standing crop (i.e., lbs of fish on hand each day) in these hatcheries is estimated at 6 to 7 million lbs. At a dietary efficiency of 65% and at an average feeding level of 3% of body weight (based upon current practices), these facilities discharge an estimated 63,000 to 73,000 lbs of biological contaminants daily into the Snake River (Klontz and King, 1975).

Based upon the foregoing, at least two problems regarding fish hatchery and farm effluents become apparent: 1) how to reduce economically the waste load in effluents from fish culture operations and 2) how to raise fish within the permitted discharge limitations.

This project was designed to define the problems, to test methods for their resolution, and to implement those methods deemed most appropriate for each particular situation. It had the following objectives:

1. To determine the rate (lbs/100 kcal metabolizable energy/lb of feed) of production of the following by rainbow trout:

   a. carbon dioxide

   b. ammonia-nitrogen

   c. phosphate-phosphorus

   d. solids (suspended and settleable)

   e. dissolved oxygen depletion

2. To determine the optimum pounds of rainbow trout per inch of body length per cubic foot of water per water change per hour.

3. To construct and test a rainbow trout production program designed to predict the time at which the following will exceed levels established for the particular situation:

a. lbs fish/inch of body length/cu ft of water/water change/hr

b. carbon dioxide

c. ammonia-nitrogen

d. phosphate-phosphorus

e. settleable solids

f. suspended solids

g. dissolved oxygen depletion

This project derived its data inputs from a highly controlled laboratory study and from field studies at the Hagerman State Hatchery, Idaho Department of Fish and Game.

References Cited

Environmental Protection Agency. 1974. Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Fish Hatcheries and Farms. National Field Investigations Center-Denver. 237 pp.

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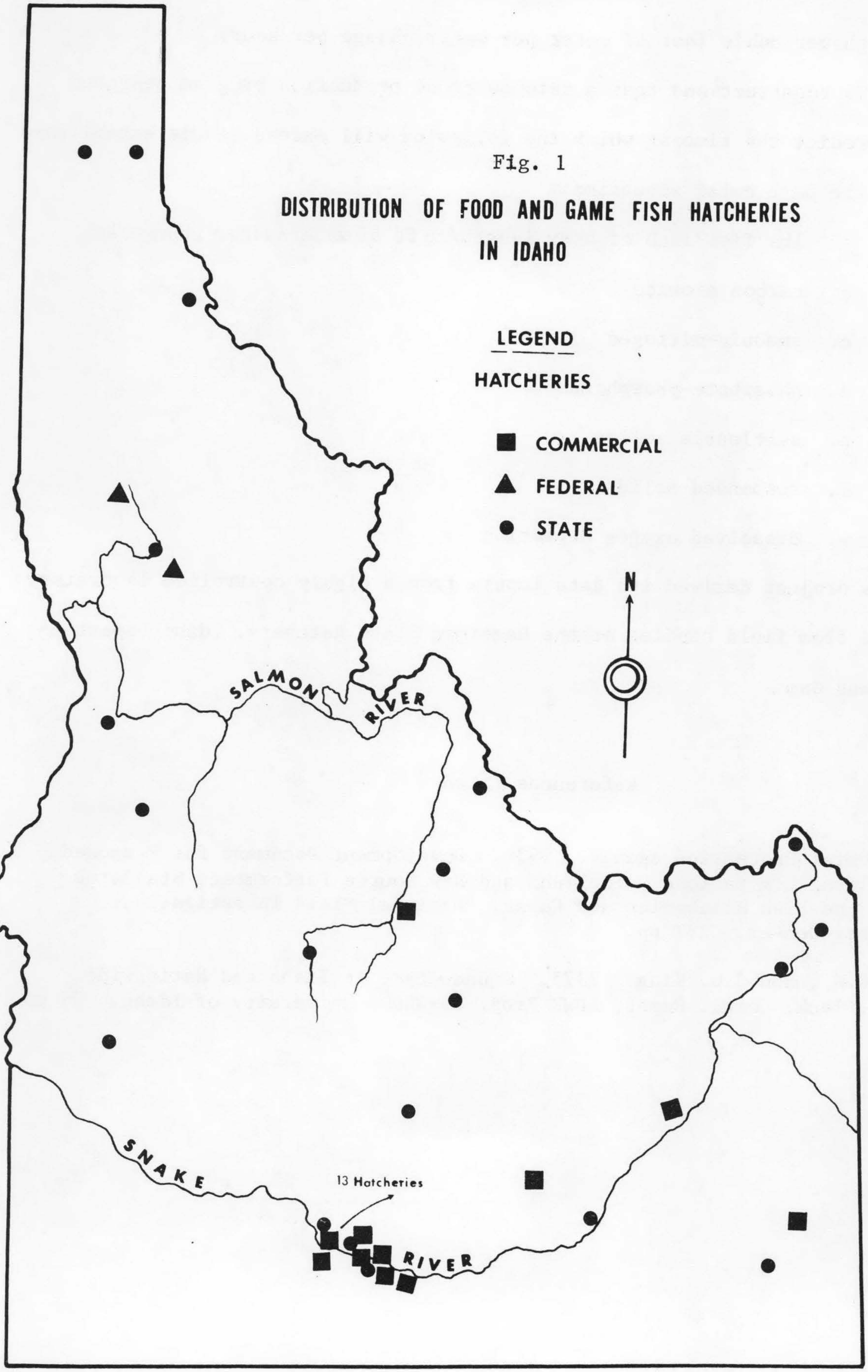
Fig. 1
DISTRIBUTION OF FOOD AND GAME FISH HATCHERIES IN IDAHO
LEGEND
HATCHERIES
COMMERCIAL
FEDERAL
STATE
N
SALMON
RIVER
SNAKE
RIVER
13 Hatcheries

II. FACTORS AFFECTING THE PRODUCTIVITY OF AN AQUACULTURE FACILITY: A COMMENTARY

In any aquaculture facility the following are identifiable as major components: fish, water, container, nutrition, management. Each has one or more interactions with each of the others and each consists of several unique factors which may or may not be present individually at any one particular facility (Table 1). Nonetheless, each, when present, can have some influence on the productivity of the facility.

The factors associated with each major component can, in most cases, be quantitated. Also, each factor must be considered as having either a cause or an effect role in relation to one or more other factors. For example, if the water depth in a pond of fish were decreased by 30% with nothing else changed, the following direct effects on the fish would occur: 1) increased swimming activity and 2) increased density (i.e., lbs of fish per cu ft of water). As a result of the increased swimming activity the following would occur: 1) increased oxygen demand, 2) increased nutritional demand and 3) decreased growth rate. The point being made is that altering one of the many variable factors in an aquaculture facility may have indirect as well as direct effects on one or more other components. To accurately assess the effects, the direct effects must be considered separately from the indirect. For example, in the original illustration, the water depth was decreased by 30% and one of the indirect effects of this on the fish was to decrease the growth rate. This effect could be offset quantitatively by increasing the feeding rate. However, what will be the effects on the fish of increasing the feeding rate? First, there will be an increased oxygen demand, in addition to the oxygen demand created by the increased swimming activity. Second, there will be an expected change in growth rate. Indirectly there will be the following effects on the environment (i.e., the water): 1) increased ammonia-nitrogen production, 2) increased solids production and 3) decreased carrying capacity. It then follows to consider what effects these environmental changes have on the fish. As can be seen, it is no easy matter to manage environmental causes and effects in an aquaculture system.

When considering several of the direct and indirect cause-and-effect interrelationships of the variables found in an aquaculture system (Table 1), it is our recommendation that a chart (Fig. 2) be constructed listing the individual variables changed along one axis and the variables affected directly and indirectly along the other axis. By ascribing the letter D for direct cause and effect and the letter I for indirect cause and effect, one can visualize the far-reaching effects of altering a variable and determine what variables can be altered.

Table 1. Interdependent and independent variables affecting fish production.

I. Fish-Associated

  A. Ammonia-nitrogen

  B. Behavior

  C. Nutritional requirements

  D. Environmental requirements

    1. Physical

    2. Chemical

  E. Growth rate

  F. Infectious disease

  G. Length-weight relationship

  H. Product definition

  I. Cannibalism

  J. Oxygen uptake

II. Water-Associated

  A. Dissolved oxygen

  B. Nitrite-nitrogen

  C. Alkalinity/Hardness

  D. pH

  E. Inflow in gallons per minute or cubic feet per second

  F. Suspended solids

  G. Settleable solids

  H. Temperature (constant or variable)

  I. Carrying capacity

  J. Agricultural contaminants

  K. Industrial contaminants

Table 1. Continued.

- L. Municipal contaminants
- M. Natural contaminants
- N. Utilization
- O. Salinity

III. Container-Associated

- A. Water volume
- B. Water velocity
- C. Composition
- D. Water flow pattern
- E. Outfall design

IV. Nutrition-Associated

- A. Feeding rate
- B. Feed efficiency
- C. Feed style
- D. Nutritional quality
  - 1. Proximate analysis
  - 2. Metabolizable energy
- E. Feed storage

V. Management-Associated

- A. Fish sampling techniques
- B. Feeding frequency
- C. Feeding techniques
- D. Record keeping
- E. Pond cleaning
- F. Fish size grading techniques
- G. Management programming
- H. Management objectives

Fig. 2. Chart of the direct (D) and indirect (I) effects of changing variables in an aquaculture system.

	Factors Affected									
Factor changed	Growth rate (ΔL)	Water velocity (R_v)	Feed demand (FD)	Water replacement (R_Δ)	Dissolved oxygen (DO)	Solids	Oxygen demand (OD)	NH_3-N	Density index (DF)	Feed conversion
Volume	I	D	I	D	I		I		D	I
Water inflow	I	D	D	D	D/I		D			
Growth rate (ΔL)			D				D			
Feeding rate	D					D	D	D		D/I
Water replacement (R_Δ)	I	D	I		D					
Dissolved oxygen (DO)	D		D							
Temperature	D/I		D				D			
Density factor (DF)	D				I		I			
Feed	D		D			D		D		D/I

III. FACTORS IN WASTE PRODUCT GENERATION: A REVIEW

Fish are nonconsumptive users of water; however, they do alter biologically the water in which they reside. The more important biological alterations include: 1) increased nitrogenous compounds (i.e., ammonia-nitrogen, nitrite-nitrogen, and nitrate-nitrogen), 2) increased carbon dioxide and phosphates, 3) increased solids - both suspended and settleable, 4) decreased dissolved oxygen and 5) increased biological oxygen demand (BOD).

The generation of waste products in an aquaculture facility consists of a rather complex series of interactions among fish, nutrition, water and management. The container component does interact to some degree but is largely dependent upon the interactions of the other components. Simplistically, the fish-nutrition interactions would seem to be the most important, but they are modified drastically by the interactions with and among the other two components.

A. The readily identifiable fish-associated factors involved in the quality and quantity of waste product generation are

1. Size: Currently, fish being raised in Idaho range in size from 1 inch to over 12 inches. The smaller fish eat more (i.e., a higher percentage of body weight) than do larger fish, but there are generally less pounds of small fish on hand at any one time. Also, the presence of small fish in a fish culture facility, especially one producing game fish, is seasonal, with the highest poundage occurring in the fall and winter.

2. Species: In Idaho, the following fishes are being reared in hatcheries and farms: rainbow trout, steelhead trout, brook trout, brown trout, cutthroat trout, kokanee, Dolly Varden trout, coho salmon,

spring chinook salmon, summer chinook salmon, grayling, channel catfish, blue catfish, Tilapia, mackinaw trout, and Kamloop trout. It has been convenient to assume that all species of salmonids are similar. In many respects they are, but each has its own unique behavior, space requirements, nutritional requirements, temperature preferences, growth rates and metabolic pathways.

3. Growth rates: Growth rates of fish are intimately dependent upon water temperature and caloric intake. Under optimal conditions for the species being raised, the growth rate of salmonids can approach 1.5 inches per month. At this level the caloric intake is approximately twice that required for what would be construed as a "normal" growth rate. Conservation hatcheries (i.e., state and federal) as a general rule grow fish at a lower rate than do commercial hatcheries. Therefore, the waste load generated in lbs per 100 lbs of fish daily from a commercial facility could be greater than that generated from a conservation facility.

B. The readily identifiable nutrition-associated factors involved in the quality and quantity of waste product generation are

1. Metabolizable energy: It is generally accepted that salmonids require 1650 kcal per lb of weight gain and that catfish require 1750 kcal per lb of weight gain. Commercially available feeds contain 1100 to 1200 kcal metabolizable energy per lb. Theoretically, then, a feed conversion (i.e., lbs of feed required per lb of gain in fish) of 1.5 to 1.375, respectively, could be expected for salmonids and 1.59 to 1.46, respectively, for catfish. This suggests that for each pound of feed fed to salmonids there is 0.33 to 0.27 lb, respectively, of waste generated. For catfish there would be 0.37 to 0.32 lb, respectively, of waste generated per lb of feed fed.

2. Feed conversion (or dietary efficiency): As has been stated, under

ideal conditions 1.375 to 1.5 lbs of feed will produce 1 lb of weight gain in salmonids. However, in practice this does not always occur. The "real life" feed conversion ranges from 1.3 to 1.5 for small fish (1-3 inches), 1.5 to 1.7 for medium-sized fish (3-8 inches), and 1.8 to 2.0 for large fish (8-12 inches). This makes estimating the waste load in discharge waters difficult.

3. Quantity: The quantity of feed fed daily is directly dependent upon the desired growth rate, fish size and dietary efficiency. This can be expressed as the lbs of feed per 100 lbs of fish, being calculated from dividing the pond constant by the length (in inches) of the fish being fed (Buterbaugh and Willoughby, 1967). The pond constant (PC) is derived by multiplying the daily length increase in inches (ΔL) by the estimated or historical feed conversion and then multiplying the result by 300. The 300 is derived from a length-weight conversion factor of 3 and a decimal-removing factor of 100. An example of feeding different lengths of fish at frequently used pond constants is presented in Table 2.

C. The readily identifiable water-associated factors involved in the quality and quantity of waste product generation are

1. Temperature: Salmonids growing at their preferred water temperature, termed the standard environmental temperature (SET), can increase their length by nearly 1.5 inches per month. For each ^{o}F decrease from their SET, salmonids decrease their metabolic rate by approximately 5% and, correspondingly, their metabolic intake and waste product output. The fish-raising facilities in the Hagerman Valley are supplied with year-round 59^{o}F water. Facilities in other parts of the state have seasonal water temperature fluctuations ranging from the low 40s to the low 60s.

Table 2. Pounds of feed[a] and pound waste generated per 100 pounds of fish at length L at different pond constants (PC)[b].

	PC = 12.5		PC = 15		PC = 17.5		PC = 20	
L	lbs feed	lbs waste	lbs feed	lbs waste	lbs feed	lbs waste	lbs feed	lbs waste
1	12.5	4.1	15.0	5.0	17.5	5.8	20.0	6.6
2	6.3	2.1	7.5	2.5	8.8	2.9	10.0	3.3
3	4.2	1.4	5.0	1.7	5.8	1.9	6.7	2.2
4	3.1	1.0	3.8	1.3	4.4	1.5	5.0	1.7
5	2.5	0.8	3.0	1.0	3.5	1.2	4.0	1.3
6	2.1	0.7	2.5	0.8	2.9	1.0	3.3	1.1
7	1.8	0.6	2.1	0.7	2.5	0.8	2.9	1.0
8	1.6	0.5	1.9	0.6	2.2	0.7	2.5	0.8
9	1.4	0.5	1.7	0.6	1.9	0.6	2.2	0.7
10	1.3	0.4	1.5	0.5	1.8	0.6	2.0	0.6

[a] Using the Buterbaugh-Willoughby (Buterbaugh and Willoughby, 1967) modification of Haskell's method (Haskell, 1959).

[b] Using the Willoughby (Willoughby, Larsen and Bowen, 1972) method.

2. Dissolved oxygen: Most fish - salmonids, in particular - require water with a minimum of 5 mg/l dissolved oxygen. At this level, growth is marginal. For optimum growth, fish-raising waters should be 95% saturated with oxygen, with both temperature and altitude affecting the oxygen-carrying capacity. Spring waters in the Hagerman Valley have dissolved oxygen levels of 9.0 to 9.3 mg/l.

As was noted earlier, small fish have a higher metabolic rate than do large fish. However, the oxygen demand in small fish decreases with age. Carrying capacities of fish raceways and ponds, in lbs per cu ft of rearing space or per gallon per minute (gpm) of water in-flow, are calculated by taking into account the amount of available dissolved oxygen and the oxygen demand for the particular size fish.

D. The readily identifiable management-associated factors involved in the quality and quantity of waste product generation are

1. Feeding techniques: In Idaho, fish are fed by hand, by truck-mounted blowers, by track-mounted blowers, by stationary mechanical feeders and by demand feeders. Each style has its unique favorable and unfavorable qualities. As a general rule, hand feeding is the least wasteful and most accurate, but the most costly from a labor standpoint. Uneaten feed contributes significantly to the solids load in the discharge and to the increasing cost of raising fish.

2. Feeding frequency: Fish fed several times each day generally perform better than do fish fed only once or twice a day. Also, there is less likelihood of wasting feed with increased feeding frequency.

3. Growth programming: This is a relatively new fish culture practice which is receiving increasing interest and application. It takes into account all the interactions of fish, water, container, nutrition and

management, so that the desired product may be obtained within the scheduled time. It also has the benefits of reducing production costs, increasing production efficiency and reducing loss-of-production potential.

4. Pond cleaning, inventorying, harvesting and grading: These acts on any fish-raising facility are often referred to collectively as "working the fish." On any occasion when fish are handled, sediments (uneaten feed, fish feces, algae, etc.) are disturbed and swept out in the discharge. More frequent cleaning of ponds decreases the sediment load, which decreases the BOD, which in turn increases the fish carrying capacity of the pond or stream below the hatchery discharge site. It should also be pointed out that any working of the fish creates a potential health hazard for the fish. The inherent stress may by itself be lethal or it may induce a latent microbial infection into a clinical outbreak, resulting in a significant economic loss.

References Cited

Buterbaugh, G. and H. Willoughby. 1967. A feeding guide for brook, brown, and rainbow trout. Prog. Fish-Cult., 29(4):210.

Haskell, D.C. 1959. Trout growth in hatcheries. New York Fish and Game Journal 6(2):204.

IV. GROWTH AND GROWTH PROGRAMMING: A REVIEW

Growth of fish in an aquaculture system can be quantitated by documenting changes in length, weight or number of fish per lb. All three are currently used by fish culturists.

Growth programming is the practice of predicting the rate of growth during a period of time termed either growth period or inventory period. It is based on the over-all gain in either lbs or inches divided by the number of growth or inventory periods available. On most facilities the growth period is 14 to 15 days, while on some it may be 30 days. For example, a conservation hatchery raising fall-spawning rainbow trout for mid-summer release into the wild as 7-inch fish will have approximately 8 to 9 months production time. Assuming that the facility has 59^{o}F water, the growth rate can exceed 0.5 inches per 14-day period. Assuming further that the fish can be ready for programmed growth (i.e., 1.35 inches or 1000/lb) 1 to 2 months after the eggs are taken, it will leave 6 to 8 months actual growth time. This means that the fish will have to grow 5.65 inches in 7 months (av.) or 0.4 inches per 14-day period. The problem now is how to manage the program with reasonable assurance of meeting the deadline.

Before dealing with the above problem specifically, there is another problem which must be considered namely, pond loading or carrying capacity. Every fish-raising facility consists of some sort of ponds into and out of which water flows to keep the fish hale and hearty. The interrelationships of pond and water flow are integral components of growth programming. The fish depend upon them for life support dissolved oxygen, for removing the accumulated excretory products (NH_3-N and solids), and for providing the environment in which the innate behavior pattern requirements of the fish are met.

To date there have been seven published methods to determine the carrying capacity of a pond (Haskell 1955, Willoughby 1968, Elliott 1969, Westers 1970, Piper 1970, Liao 1971, Piper 1972). Each of the seven takes into account two or more of the following variables occurring in the system (Appendix I):

1. Fish-associated
    a. growth rate
    b. weight
    c. length
    d. oxygen uptake
2. Pond-associated
    a. volume
    b. density index
3. Water-associated
    a. inflow
    b. changes per hour
    c. temperature
    d. dissolved oxygen
    e. elevation
    f. lbs fish/gallons per minute
    g. lbs fish/cu ft water
    h. lbs fish/pond
4. Feed-associated
    a. feeding rate

Carrying capacity values obtained from applying each method to a fish-raising system appear quite realistic when viewed individually; however, a wide disparity among values is seen when the individual values are viewed collectively (Table 3). The primary reason for this disparity lies in the

Table 3. Comparison of reported fish pond loading calculations using different methods of calculation.

Pond:	1920 cu ft (8 ft x 80 ft x 3 ft)
Fish:	6 inch rainbow trout (0.086 lb each) (K-factor = 4.05×10^{-4})
Water temperature:	$58^{o}F$
Dissolved oxygen:	9.8 mg/1
Elevation:	1000 ft above mean sea level
Water flow:	1.07 cfs (481.5 gpm)
Water changes/hr:	2.0
Max. feed/cu ft:	0.05
Feeding rate (R_f):	2.4%

Method*	Lbs fish in pond
Haskell	4000
Willoughby	5725
Westers	5376
Piper (Load Factor)	3813
Liao	3263
Piper (Density factor = 0.5)	5760
Mean	4656
Range	3263-5760

*See references cited.

factors taken into account by the individual methods (Table 4).

Haskell's Feeding Level method estimates the carrying capacity from historical data on how many lbs of feed can be fed per cu ft of water, the limits to which are based upon the available dissolved oxygen. Then, by dividing the estimated feeding rate into the lbs of feed permitted and multiplying the result by the cu ft available, the maximum number of lbs of fish that the pond will support is estimated (Haskell 1955).

Willoughby's Feeding Level method is similar to Haskell's in that it is based upon the lbs of feed that can be metabolized by fish in the pond. The amount of feed is estimated from the available dissolved oxygen (DO) rather than from historical data. DO is calculated from the differences between inflow and outfall oxygen levels. The feeding rate is determined from the ΔL method (Haskell 1959).

Westers' Water Replacement Time method estimates pond loading based upon lbs of fish per gpm (W_{gpm}) times the water changes per hour (R_{Δ}) times the volume (V), all divided by 8 (a factor converting gpm to cfh). W_{gpm} is obtained from a series of temperature-correlated graphs considering lbs of fish per cu ft, fish length and R_{Δ}.

Elliott's Oxygen Uptake method estimates the pounds of fish per gpm by dividing the oxygen demand for a fish of specified weight into the available DO. The method was derived for chinook salmon fingerlings.

Piper's Load Factor method estimates the pond loading based upon the lbs of fish per gpm per inch of fish (F) times the gpm inflow (I) times the length of the fish. F was derived empirically and corrected for water temperature and quality evaluation to correspond to the amount of available dissolved oxygen.

Liao's Oxygen Consumption method estimates pond loading based upon the oxygen consumption of a fish of specified weight, the DO available and the water

Table 4. Factors considered by the 7 published methods of calculating fish carrying capacity.

Factor	Method*						
	Haskell	Willoughby	Westers	Elliott	Piper (1970)	Liao	Piper (1972)
Pond volume	XX		XX				XX
Water inflow		XX	XX		XX	XX	
Water changes per hour			XX				
Water temperature				XX	XX	XX	
Dissolved oxygen		XX		XX	XX	XX	
Elevation					XX	XX	
Fish length					XX		XX
Fish weight						XX	
Density index							XX
Lbs fish/gpm			XX	XX	XX	XX	
Lbs fish/cu ft	XX		XX				
Oxygen uptake		XX		XX		XX	
Lbs fish/pond		XX	XX		XX	XX	XX
Growth rate	XX						
Feeding rate	XX	XX					

* See references cited.

inflow. When comparing the pond loading for rainbow trout using this method with that obtained using Piper's Load Factor method, Liao's estimate is 16.3% less than Piper's, regardless of the pond volume of water inflow. However, when the same pond data are used with chinook salmon the differences are very irregular.

Piper's Density Index method estimates pond loading based upon the space factor requirement for the species of fish in question. For example, rainbow trout grow well at a density of 0.5 lbs of fish per cu ft of water per inch of body length. Cutthroat perform well at a density of 0.3 lbs per cu ft per inch of body length. This density factor takes into account only the psychological requirements of the fish in question - i.e., some fish can stand crowded conditions and some cannot. In this method there is no consideration of life support parameters. To apply this method, the life support capabilities of the pond must be balanced with the space capabilities of the pond.

One definition of carrying capacity is the maximum quantity of fish able to remain healthy in a system. Implicit in this definition is the understanding that if the carrying capacity of the system is exceeded the rate of fish growth will be decreased. Implicit also is the fact that the system must be loaded initially with an amount of fish that, when fed to provide a specified growth rate, will not exceed the carrying capacity of the system too soon. Unfortunately, there is no loading method available which takes growth into account.

During the past two decades a great deal of research - both basic and applied - has been conducted on the subject of fish growth (Halver 1972). As a result, the basic nutritional requirements for salmonids and, to some degree, ictalurids have been established. These data, perhaps, do not have too much pragmatic value for the average fish culturist, since he feeds his fish a commercially prepared ration rather than preparing his own. The concern of the fish culturist is how to feed a prepared diet to produce a fish of desired size within a prescribed time period. There have been several methods offered and each merits some consideration.

Schäeperclaus (1933), among the first to offer a method of feeding fish quantitatively, considered the calories required for growth based upon body surface, water temperature and the hourly caloric intake requirements. He calculated the body surface in square decimeters (1 dm = 10 cm) for trout as being equal to 10 times the body weight in grams to the 2/3 power. The caloric needs of trout were estimated at 1.44 gram-calories (gcal) per dm^2 per day. Other fish nutritionists have subsequently offered methods of feeding based upon the caloric requirements of fish (Phillips and Brockway 1959; Brown 1957; Winberg 1960; Paloheimo and Dickie 1956, 1966a, 1966b). Application of these methods presumed that the caloric values of the rations were known.

The development of the "hatchery feeding chart," which relates the amount of feed to the fish size and water temperature, removed the necessity of knowning the caloric value of the feed (Deuel, Haskell and Tunison 1937; Deuel et al. 1952). These charts have withstood the test of time, and modifications of the basic charts are currently offered by virtually every fish feed manufacturer (Table 5). However, use of the chart was considered by some to be too rigid a program to permit inclusion of other variables influencing growth which were unique to one facility or another. To this end, two methods of feeding were offered, either of which allowed the fish culturist the latitude of his particular situation. One was the ΔL concept (Haskell 1959) and the other was based upon the estimated weight gain (Freeman et al. 1967).

Haskell (1959) considered the major factors affecting fish growth to be water temperature, fish species and feeding rate. His calculations of feeding rate took into consideration the K-factor of the fish, the ΔL and the anticipated feed conversion.

Table 5. Recommended feeding rates (lbs feed/100 lbs fish) for salmonids raised in conservation hatcheries. (Modified from the Deuel et al. method 1952.)

Water Temp. (^{o}F)	Approximate Size (inches)										
	1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-
39	3.0	2.5	2.2	1.7	1.3	0.9	0.8	0.7	0.6	0.6	0.5
41	3.3	2.8	2.2	1.8	1.4	1.1	0.9	0.8	0.7	0.6	0.5
43	3.6	3.0	2.5	1.9	1.4	1.2	1.0	0.9	0.8	0.7	0.6
45	4.0	3.3	2.7	2.1	1.6	1.3	1.1	1.0	0.9	0.8	0.7
47	4.3	3.6	3.0	2.3	1.7	1.4	1.2	1.0	0.9	0.8	0.7
49	4.7	3.9	3.2	2.5	1.9	1.5	1.3	1.1	1.0	0.9	0.8
51	5.4	4.5	3.5	2.8	2.1	1.7	1.5	1.3	1.1	1.0	0.9
53	5.6	4.7	3.8	2.9	2.2	1.8	1.5	1.3	1.1	1.1	1.0
55	6.1	5.1	4.2	3.2	2.4	2.0	1.6	1.4	1.3	1.1	1.0
57	6.7	5.5	4.5	3.5	2.6	2.1	1.8	1.5	1.4	1.2	1.1
59	7.3	6.0	5.0	3.7	2.8	2.3	1.9	1.7	1.5	1.3	1.2

Mathematically stated,

$$\text{Feeding rate as \% body weight} = \frac{\text{feed conversion factor} \times \Delta L \times 3 \times 100}{L}$$

where ΔL = the daily length increase (inches),

3 = weight-length conversion factor,

100 = decimal-removing factor,

L = the length (inches) of the fish on the particular day.

By assuming that at a constant water temperature, ΔL is constant, then the daily feed rate can be estimated by adding the ΔL to each succeeding daily length. For example, if the ΔL is 0.03 inches/day and the starting L was 3 inches, then the 10th day L would be 3 + 10(0.03) or 10.3 inches.

However, since very few hatcheries have constant water temperature throughout the growing period, Haskell developed a method to adjust the feeding rate estimations according to water temperatures. He found that brook trout growth, for all intents and purposes, ceased at 38.6°F and from this developed the concept of the temperature unit (TU), which was defined as the average water temperature for a month which exceeds 38.6°F by 1°F. Thus, TU = average monthly water temperature ($^{\circ}$F) -38.6°F. It then follows that an average water temperature of 55°F would have a monthly TU of 16.4° and an average water temperature of 46.8°F would have a monthly TU of 8.2°. From that, one could say that it would take 2 months at the lower water temperature to increase the length or weight of the fish the same amount as it would increase during 1 month at the higher temperature. By applying this concept, one can estimate the number of TUs required per inch of gain and then by knowing the expected TU during the growth period, the expected growth during the period can be estimated.

Parenthetically, we would like to leave the historical presentation for a bit to amplify Haskell's findings with some current observations. In determining that trout growth virtually ceases at 38.6°F, Haskell provided the basis for a valuable concept. Although it has not been stated quantitatively in so many words, each species of fish has a preferred temperature, which has been termed the standard environmental temperature (SET). For rainbow trout this has been estimated to be 59°F (15°C). For years fish culturists have said that for each °F decrease there is a 5% decrease in growth rate in rainbow trout. (For each °C decrease there is a 9% decrease in growth rate.) Accordingly, if the average monthly water temperature decreased by 5°F, in a succeeding month there would be a 25% decrease in growth rate. This concept concurs with Haskell's TU theory very well. Translating this to Pacific salmon is realistically possible. Chinook salmon are considered to have a SET of 54°F and their zero-growth level is considered to be 34°F - i.e., a 20°F drop. The same principle applies to channel catfish and coho salmon, as best we can estimate.

To remove some of the work in calculating feeding rates by Haskell's method, Buterbaugh and Willoughby (1967) developed a hatchery feeding chart based upon the hatchery constant (HC) concept. They defined the hatchery constant as the numerator of Haskell's equation; i.e., HC = feed conversion factor x ΔL x 3 x 100. For variable water temperatures the expected ΔL is calculated as follows:

$$L = \frac{\text{TU expected (month)}}{\text{TU required for 1 inch growth}} \div 30 \text{ days}$$

The daily feeding rate is estimated by dividing the hatchery constant by the length (estimated daily) of the fish.

Using the concept of hatchery constant developed by Buterbaugh and Willoughby, Piper (1970b) substituted a slide rule modification for the use of lengthy tables. The hatchery constant is set up on the D scale by aligning the index of the CI scale with the selected HC. The length of the fish to be fed is read off the D scale using the slide hairline. The percent body weight to be fed is read off the CI scale for the appropriate length of fish.

In recent years some facilities have been using computer programming to estimate the daily amount of feed required in a system. None of these, to our knowledge, has been published. They all employ the ΔL concept, with the daily increases in length and feed being printed out for each day in the growth period. There have been two major constraints to growth forecasting. The first is obtaining an accurate and realistic growth rate and the second is obtaining accurate input data - i.e., pound-count, head-count, pond weight and anticipated feed conversion.

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V. DESCRIPTION OF GENERAL APPROACH TO THE STUDY

A. Background

At the outset of this study the intent was to establish a predictable model for waste product generation for use in any aquaculture system. As the study progressed, however, the subject of growth and growth rates became the central issue rather than the waste products generated.

The design of this study includes 1) a method to evaluate growth of rainbow trout fed commercially prepared diets, 2) the effects of population density and water replacement time on growth, 3) the effects of density and growth rate on oxygen consumption, and 4) a method to realistically predict daily solids production in an aquaculture system.

B. Study Approach

1. Fish: Two strains of rainbow trout were used in the study. One was the typical rainbow trout raised at most public and private hatcheries and the other was the Kamloop strain of rainbow trout. Eyed eggs of both strains were obtained from Troutlodge, Tacoma, Washington. The rainbow trout eggs were incubated and raised at the Idaho Department of Fish and Game Hatchery at Hagerman and the Kamloop eggs were incubated and raised in the experimental facilities on the University of Idaho campus.

Both strains of trout performed very well during the course of the study, despite the usual mishaps one encounters when using fish as biological research subjects. The most frequent mishap was the plugging of the water inlet with the aquatic slime bacteria, Sphaerotilus sp., which was ultimately controlled by changing water systems. Samples of fish were examined on inventory days for the presence of infectious and noninfectious diseases. The following examinations were made: gross, wet mounts of gill filaments, hematology, bacteriology and virology (where indicated).

Population densities were set and maintained in accordance with the individual study protocols.

2. Water: Throughout the study two water temperatures were used: 59°F (55°C) and 55°F (12.5°C). The water at the Idaho Department of Fish and Game hatchery at Hagerman was a constant 59°F. The experimental facilities on the University of Idaho campus use dechlorinated and iron-filtered water which can be heated or chilled to any selected temperature and both 55°F and 59°F waters were used. The dissolved oxygen levels were maintained at both sites in excess of 95% saturation for the elevation and temperature selected.

The water use at the Hagerman facility was single-pass with no reuse, while that at the University of Idaho facilities was either a closed system with 10 to 15% make-up or an open, multiple reuse system. Water flows were set and maintained in accordance with the individual study protocols.

3. Container: Sixteen tanks, each constructed of ¼-inch plate glass and measuring 18 x 18 x 24 inches, were arranged into two eight-tank systems (Fig. 3). Each tank received a regulated amount of water from a head pipe filled under pressure from the hatchery supply. The outflow of each tank was through a Venturi standpipe system.

In addition, at Hagerman, concrete deep tanks (15 ft x 32 inches x 27 inches water depth, or 90 cu ft) were used in one portion of the study to compare the growth values obtained in the small units with those obtained in a larger unit.

4. Nutrition: Commercially prepared diets were used throughout the study. Since the purpose of the study was to test methods of diet evaluation, nutrient utilization, growth rate estimation and waste product generation, and not to compare the relative efficacies of two or more diets, the brand names are not given. The diets were labelled "A" and "B", with the pellet sizes of

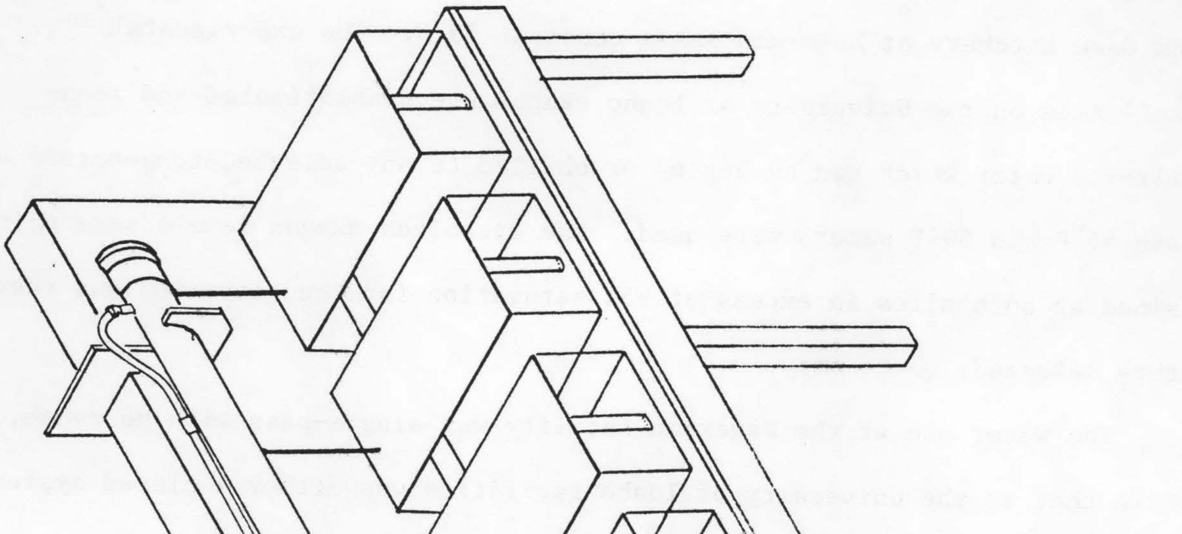

Fig. 3. Schematic of a 4-tank system which was expanded to an 8-tank unit for this study. Water use is a closed system with make-up.

each listed numerically following the letter. During the study, fish were fed four pellet sizes for each diet.

Proximate analyses of freshly prepared feed were conducted by Agra-Test, Inc., Twin Falls, Idaho (Table 6). Dried fecal samples were also analyzed for proximate composition (Table 7). Adiabatic bomb calorimetries were conducted on feed and fecal samples at the University of Idaho. In all cases, samples were identified by code designation only.

Fecal samples were collected by two methods. One was a daily collection of the entire fecal load over a 14-day period. This was accomplished by passing the tank outfall through a fine (20 μm) mesh sock. The entire daily collection was air-dried in the sock, removed, weighed and stored frozen until analyzed. The other method was to collect spot samples of feces immediately after passage from the fish. The collection was done with a siphon tube flowing into either a fine mesh sock or a centrifuge tube. The sample was dewatered by drying in the collection sock or by decanting following centrifugation, and stored frozen until analyzed.

There are several potential sources of error in the fecal collection methods. The major one in the collection of the entire daily load was the possible leaching out of water-soluble components, plus the growth of bacteria and fungi. This source of error was minimized by changing the collecting socks frequently. Comparison of the daily method analyses with the spot sample method analyses indicated no apparent error in determination of proximate composition and gross energy. Also, a surprising degree of correlation was obtained between the weight of the dried feces and the apparent digestibility coefficients.

Nutrition data were analyzed using established methods in animal nutrition (Church and Pond 1974) and fish nutrition (Rumsey 1977). The following analytic

Table 6. Proximate analyses of fish diets by type and size.

Diet	% Crude protein	%N	%Fat	%NFE	%Fiber	%Ash	Gross energy (kcal/g)
A-3	52.5	8.4	10.3	21.4	2.1	13.7	-
4	52.5	8.4	10.3	22.3	2.2	12.7	4.67
5	43.1	6.5	7.3	33.0	4.3	12.3	-
6	44.4	7.1	7.3	31.0	4.9	12.4	4.50
B-2	53.8	8.6	11.5	20.3	1.2	13.2	-
3	50.6	8.1	11.7	22.8	2.3	12.6	4.82
4	46.9	7.5	11.7	28.4	3.8	9.2	-
5	47.5	7.6	10.8	27.9	3.5	10.3	4.72

Table 7. Proximate analyses of fish feces by type of diet and pellet size.

Diet	% Crude protein	%N	%Fat	%NFE	%Fiber	%Ash	Gross energy (kcal/g)
A-4	26.9	4.3	4.2	20.7	7.1	41.1	3.10
A-5	36.3	5.8	1.5	35.2	13.6	13.5	-
A-6	25.6	4.1	1.7	37.6	17.3	17.8	3.04
B-3	36.3	5.8	5.8	23.7	13.7	20.6	2.96
B-5	21.3	3.4	3.1	33.8	16.8	25.1	3.14

equations were used:

a. Digestibility (%) = $\frac{NI - NF}{NI} \times 100$

where NI = total intake (g) of nutrient (i.e., diet, protein, fat or NFE during a growth period),

NF = total output (g) in feces of nutrient (i.e., diet, protein, fat or NFE during a growth period).

b. Protein Efficiency Ration (PER) = $\frac{\text{weight gain (g)}}{\text{protein intake (g) during growth period}}$

c. Digestible Energy (DE) (kcal/g of diet) = $GE_d - GE_f$

where GE_d = gross energy (kcal/g) of diet,

GE_f = gross energy (kcal/g) of feces.

d. Total Digestible Nutrient (TDN) = DCP + DNFE + DCF + 2.25 DEE

where DCP = digestible crude protein (% or g),

DNFE = digestible NFE (% or g),

DCF = digestible fiber (% or g),

DEE = digestible ether extract (fats) (% or g).

5. Management: Growth rates were programmed for 14-day periods, using either the OWRT computer program (Appendix II) or the BROCK computer program (Appendix III). A third computer program (IRV) was developed from the data obtained from this study, but has not been tested under field conditions (Appendix IV).

The OWRT program is a specialized program in which fish are raised to attain the maximum population density (based upon density index or life support) at the end of each growth period. It has very little application outside this study.

The BROCK program was designed to permit the user a choice of methods to determine carrying capacity - i.e., Piper Flow Index method, Liao Oxygen Consumption method, Willoughby Feeding Rate method, Pond Loading Index method, Piper Density Index method or Westers' Water Replacement Time method (Appendix I). All these methods except the Pond Loading Index method (PLI) have been discussed in Section IV. The PLI method was developed and tested during this study, The input feeding rate was based upon Haskell's ΔL concept, which implies that a reasonable growth rate must be estimated. The program will print out daily pond weight, number fish/lb, length (inches), feeding rate, lbs of feed and head-count. If the average daily mortality can be estimated, it will be considered in the daily print-out for the growth period. The program is designed to have maximum loading at the end of the growth period and initial loading is back-calculated within the program. That is, at the end of the growing period, it will be necessary to remove fish from the pond.

The IRV program is similar to the BROCK program except that it will print out daily solids (lbs/100 lbs of fish), daily NH_3-N (mg/l) and daily free NH_3 (mg/l). The ammonia-N calculations are based upon the method by Willoughby, Larsen and Bowen (1972), using the NH_3 association-dissociation table by Trussell (1972). The solids calculation is based upon the method developed during this study (Appendix VI).

At the end of a 14-day period, tank or pond inventories were conducted using both sample counting techniques and whole population inventory methods. A comparison of the two methods will be presented.

Feeding fequencies (number of feedings per day) were dependent upon the size of the fish being fed and the feeding level. Because of their smaller stomach capacity, small fish on a high feeding level received more frequent feedings each day than did either the same size fish on a lower feeding level or larger fish at the same growth rate.

Estimations of growth rate were, at the outset, based upon 70% and 90% of the growth rate considered to be maximum at the particular water temperature. Later in this study another method of estimating growth rate was tested and found to be promising.

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VI. THE EFFECT OF DENSITY AND GROWTH RATE ON THE WEIGHT-DEPENDENT OXYGEN CONSUMPTION: A STUDY

A. Background

In the past 25 years, the relation of body weight to oxygen consumption in fishes has received a great deal of attention (Job 1955, 1959, 1969; Winberg 1956; Fry 1957; Basu 1959; Beamish 1964a, b; Beamish and Mookherjii 1964; Brett 1964, 1965; Kutty 1968; Elliot 1969; Liao 1971). However, very little of this work has dealt with the metabolic response of fishes to various densities and growth rates, two of the most important factors dealt with in fish culture. They give rise to such questions as:

Will the added stress on fish held at high density cause them to use more or less oxygen per unit biomass than the same fish held at lower density?

Do fish growing at a high rate require more oxygen than do fish growing at a low rate?

These two questions must be answered to help fish culturists better understand the needs of the fish being reared. The purpose of this study was to determine the effects of density, growth rate, and the interactions between density and growth rate on the oxygen consumption of rainbow trout.

The study was also designed to test the efficacy of a new method of determining oxygen uptake. Most of the published studies were conducted using specially constructed respiratory chambers into which a small number of fish could be placed and allowed to acclimate for 8 to 48 hours. The practice of moving fish from their normal environment, be it hatchery rearing pond or stream, into a completely new and different environment to do oxygen consumption tests has been questionable. Schäeperclaus (1933) showed three-fold increase in oxygen consumption by tench after transference from a pond to a barrel. This suggests that a change in environment causes stress or excitement, leading to a very large change in the fish's oxygen requirements.

In this study, a new approach was used to remove handling stress and the need for adaptation to a new environment as possible sources of error. The oxygen consumption tests were run with the entire lot in the same tanks in which they were being reared. Standard hatchery conditions were duplicated as much as possible, so that the data gathered could actually be used in a field situation.

B. Study Approach

1. Experimental Fish: Rainbow trout, obtained from the Idaho Department of Fish and Game trout hatchery at Hagerman, were from two separate lots being reared there at the time. The lots were labelled A and A', with lot A fish having an average initial weight of 4.340 g and lot A' fish having an average weight of 0.387 g. The fish were reared through four 2-week periods.

2. Fish Holding Facilities: These were described in section V.

3. Oxygen Consumption Procedure: The oxygen consumption tests were run during the afternoon proceding an inventory sampling day. The fish were not fed for 20 to 22 hours prior to testing. For 2 weeks before and during the test, the fish were not handled. A YSI Dissolved Oxygen Meter (Model 54 ARC) and probe were used to measure oxygen uptake in the tank. The test tank was filled with water, then sealed with a special glass lid, the inside of which was covered with porous foam rubber that allowed water to penetrate, thereby moving the air-water interface out of the fish's range (Fig. 4). The lid also had a hole drilled in the center to allow entry of the oxygen probe. Readings of dissolved oxygen were taken initially, then

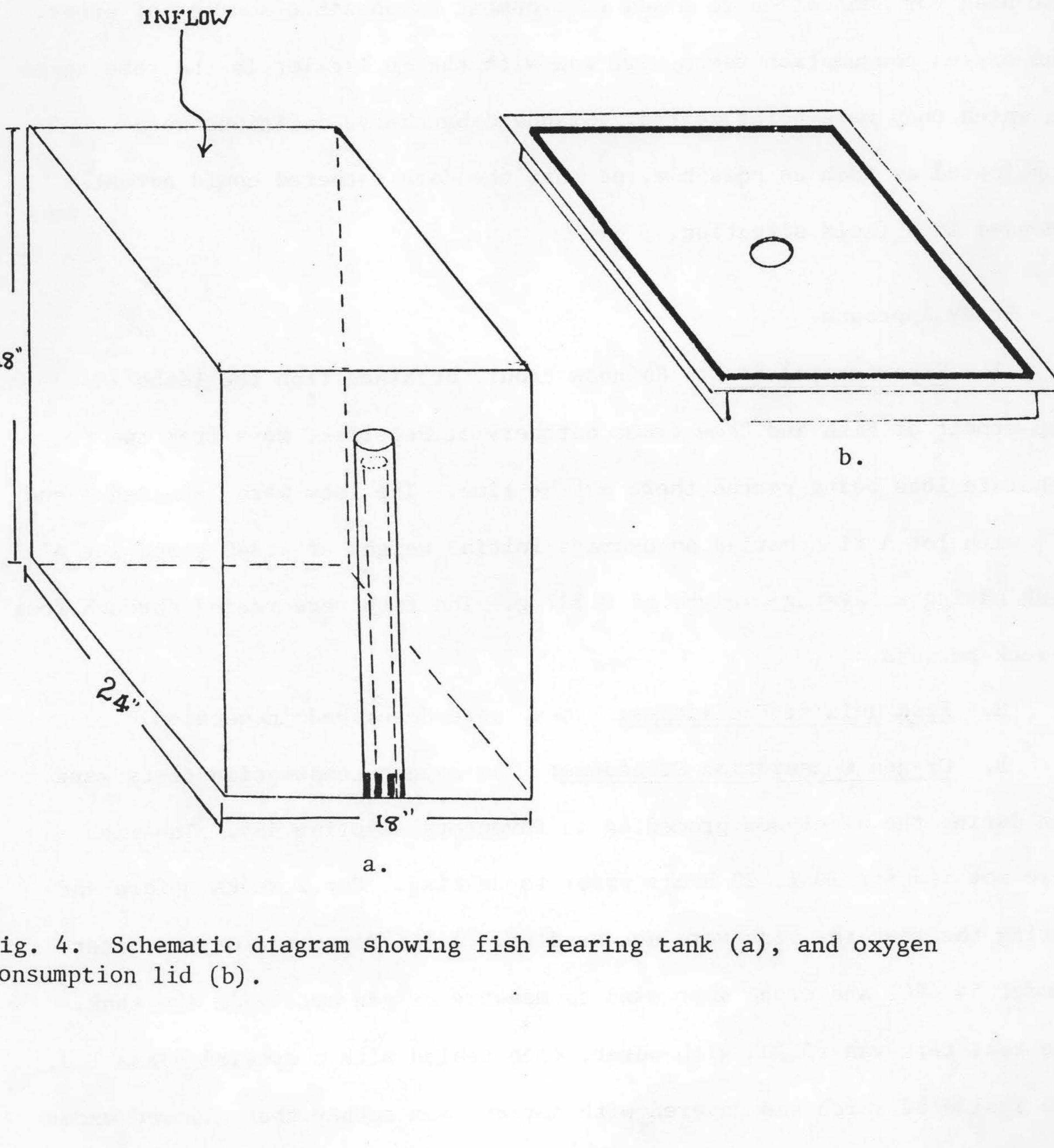

Fig. 4. Schematic diagram showing fish rearing tank (a), and oxygen consumption lid (b).

at 10-minute intervals until either the dissolved oxygen had reached a level of 4 mg/l or 30 minutes had passed. The oxygen consumptions in mg oxygen per kg of fish per hour and mg oxygen per hour were computed as follows:

$$\text{mg } O_2/\text{hr} = \frac{[V(O_i - O_f)]\,(60/t)}{N}$$

$$\text{mg } O_2/\text{kg fish/hr} = \frac{[V(O_i - O_f)]\,(60/t)}{B}$$

Where V = volume of water in the test tank,

O_i = initial oxygen level (mg/l),

O_f = final oxygen level (mg/l),

N = number of fish in the tank,

B = biomass of fish in the tank (kg),

t = time between the initial and final oxygen readings (min).

4. Experimental Design: Three variables were introduced into each system: maximum density index (MDI), feed rate (R_f) and water inflow (R_w). Two density levels were tested, 0.2 and 0.5 lbs of fish per cu ft water per inch body length. These densities were selected to represent those typical of a conservation hatchery (0.2) and of a commercial hatchery (0.5), respectively.

Two growth rates were selected, since fish culturists must sometimes either increase or decrease growth rates in the fish they are rearing. Assuming maximum growth for rainbow trout to be 1.5 inches per month at 59^{o}F, the two groups were fed to attain 70% and 90% of this, or 1.05 and 1.35 inches per month (corresponding to daily growth of 0.035 and 0.045 inches, respectively). A food conversion ratio of 1.2 was assumed for the smaller fish and 1.5 for the larger fish. The fish were fed a commercially prepared diet several times daily.

Water inflow (in gpm) was determined using the newly developed pond loading index formula (cf Section VIII). This permits adjustment of the inflow to meet the life support requirements of the fish in the pond. For example, in two identical ponds, one loaded at a density of 0.2 and the other at 0.4 lbs per cu ft per inch of body length, all other factors constant, the first pond would require half the life support of the second pond. All possible combinations of density, feed rate and inflow were made in at least one tank, but in this study, only tanks which had the water inflow adjusted to meet life support were used.

The fish were sampled every 2 weeks for weight gain, length gain, gill condition, number per lb and dietary efficiency. The day before sampling, the fish received no feed, and it was on this day that oxygen consumption tests were run. Data collected were processed through the University of Idaho Computer Center by means of an on-site portable computer terminal. The program used was written specifically for this study (Appendix II) and performed all of the pond loading and feeding calculations needed for the next 2-week period (Appendix V). Fish were removed from each tank at the start of each inventory period to maintain the specified MDI. The tanks were cleaned daily and the fish fed 8 to 10 times daily.

C. Results and Discussion

The general equation relating metabolic rate (Y, mg O_2/hr) to weight (X, grams) has been expressed as $Y = aX^b$, or $\log Y = \log a + b \log X$ (Brett 1965). Using this transformation with the oxygen consumption data collected, and using a standard least squares regression, the slope values (b, the rate of change of metabolic rate with size) can be computed. The data were also subjected to a factorial analysis of covariance (Steel and Torrie 1960). If all the data are treated together, a b-value of 0.8423 is the result. Slopes (b-values) for high and low density, as well as for high and low feed rates, are also found in Table 8.

These data are in agreement with those found in the literature for fishes. Lagler et al. (1977) state that b-values between 0.6 and 1.0 are common for fishes. Barrett (cited by Fry 1957) obtained a slope of 0.8 for rainbow trout, as did Coche (1967), who reported a slope value of 0.8 for steelhead (*Salmo gairdneri*). Brett (1965) reported a slope value of 0.778 at 15°C in fresh water for *Oncorhynchus nerka*. Huesner et al. (cited by Madan Mohan Rao 1971) obtained mean slope values of 0.7, 0.8 and 0.7 at 25°C for three species. Madan Mohan Rao (1971) reports b-values of 0.7838 in 5°C fresh water and 0.7834 in 15°C fresh water for rainbow trout. Beamish (1964b) and Beamish and Mookherjii (1964) cited b-values of 0.88 for *Salmo trutta*, 1.05 for *Salvelinus fontinalis*, 0.86 for *Catastomous commersoni*, 0.93 for *Ictaluris nebulosis* and 0.85 for *Carrassius auratus* (over-all mean of 0.9).

The close correlation between our findings and those of other studies has a dual meaning: it corroborates the methods used in previous work and validates the results of the new oxygen consumption method. This indicates that 8 to 48 hours was indeed enough time for the fish to become acclimated to their new environment, and that the procedure used in this study provides a new and accurate method of determining oxygen consumption. Our new oxygen consumption procedure allows testing the effects of various fish culture manipulations on oxygen consumption in a simulated hatchery pond. This procedure also eliminates the need for using more expensive respiratory flow chambers.

Table 8. Equations for relationship between metabolic rate (Y, mg O_2/hr) and weight (X, grams) at different levels of density and feed rate. Also included is an equation for a combination of all data gathered.

Variable	Equation	Correlation (r)
Low Density	$\log Y = -0.3204 + 0.8441 \log X$	0.9884
High Density	$\log Y = -0.2865 + 0.8165 \log X$	0.9943
Low Feed Rate	$\log Y = -0.3022 + 0.8106 \log X$	0.9904
High Feed Rate	$\log Y = -0.3224 + 0.8699 \log X$	0.9941
Combined	$\log Y = -0.3128 + 0.8423 \log X$	0.9916

1. The Effect of Density on Oxygen Consumption: It can be seen from the graphic presentation of the data that the rate of oxygen consumption at both densities is virtually the same (Fig. 5). The factorial analysis of covariance run on the data showed no significant effect ($P < 0.01$) on oxygen consumption by the change in density.

Rainbow trout are territorial fish, and the data indicate that territoriality was not broken down even at the high density level. This conclusion is supported by actual observation of fish behavior in both the high and low density tanks. If territoriality were broken down, we assume that oxygen consumption would increase due to increased activity and stress on the fish. One might also assume that, because the fish in the low density tanks would have larger territories, they would move around more or be more active in the territory, thereby using more oxygen. This is apparently not the case.

2. The Effect of Growth Rate on Oxygen Consumption: Growth rate has little or no effect on the rate of oxygen consumption (Fig. 6), as shown by an F-value of 0.0. This can be explained by the fact that the fish had been starved for 20 to 22 hours before oxygen consumption tests were run. We believe that this timing factor was sufficient under our given water temperature (59°F) to allow metabolism to reach a baseline level which was virtually

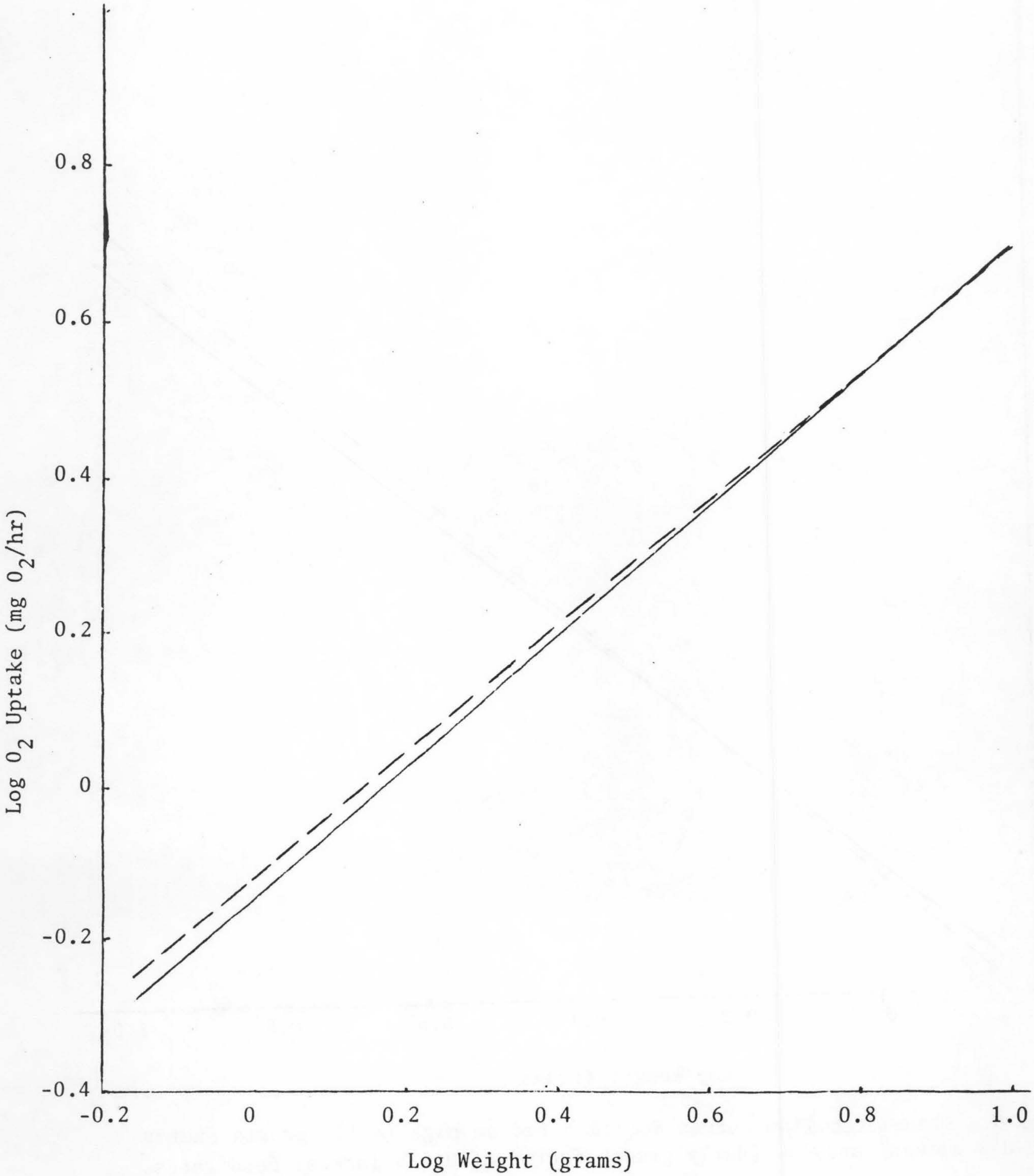

Fig. 5. Size-metabolism curves for fish held at high density (0.5 lb/cu ft/inch) and low density (0.2 lb/cu ft/inch). Solid line is low density and dotted line is high density.

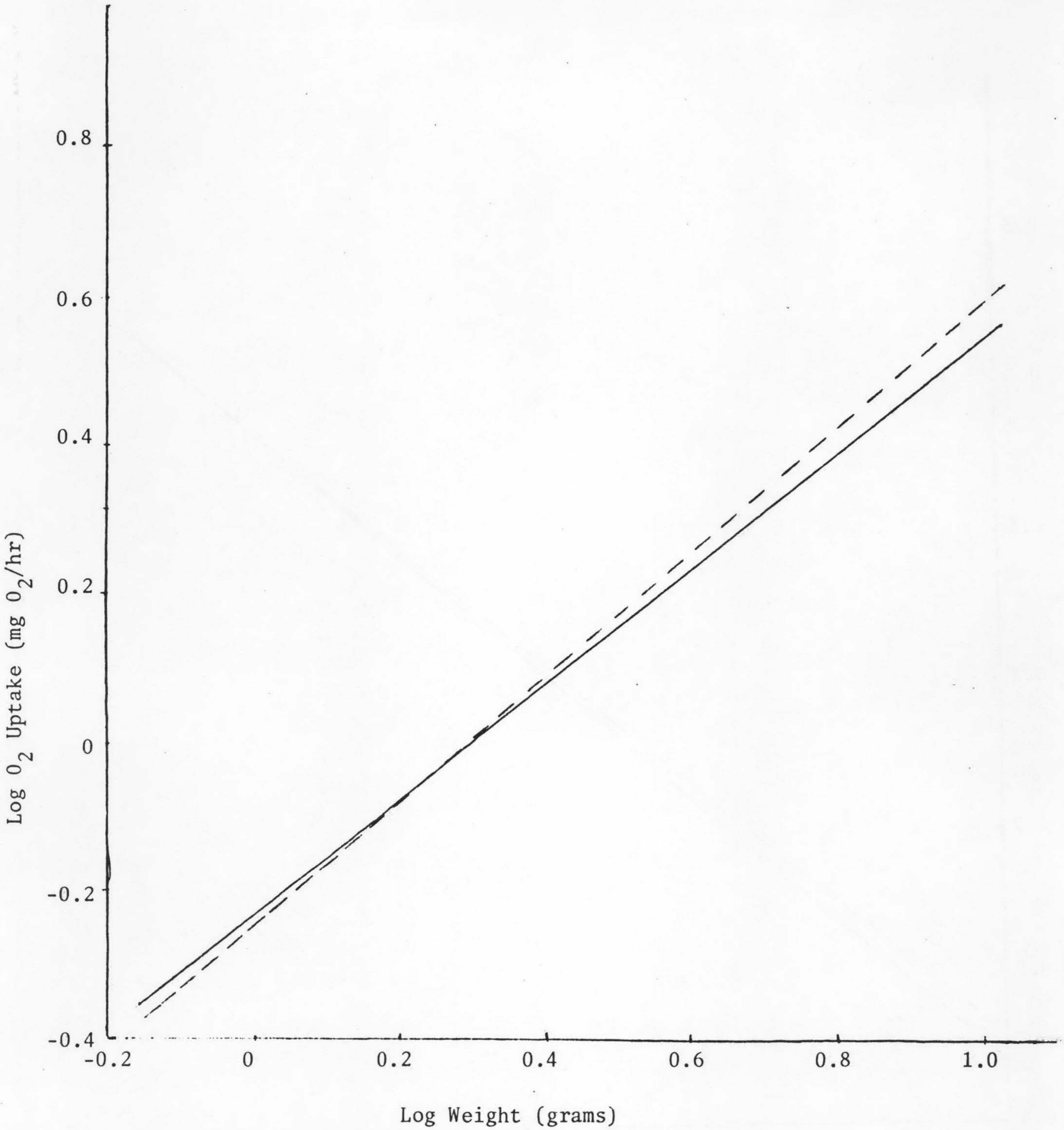

Fig. 6. Size-metabolism curves for fish fed at high (daily growth factor of 0.045 inches) and low (daily growth factor of 0.035 inches) feed rates.

identical for the high and low growth rates. Wells (1935) did not find a significant change in the rate of oxygen consumption of Girella nigricans beyond 24 hours of starvation. No further change in the rate of oxygen consumption could be detected after two days of starvation by Moss and Scott (1961). Beamish (1964a) stated that a comparison of the average routine and average standard rates of oxygen consumption indicates that, at both levels of activity, oxygen consumption decreased with starvation during the first 2 or 3 days. Beyond this there was no further decrease at the standard level, whereas average routine oxygen consumption continued to decrease, although not at as high a rate.

3. The Effect of the Interaction Between Density and Growth Rate: There was no significant effect ($P < 0.01$) on oxygen consumption caused by any interaction between growth rate and density (F-value = 0.808).

D. Implications

Oxygen uptake per unit biomass decreases as individual fish weight increases (Fig. 7). This was also found by Brett (1965), Madan Mohan Rao (1971) and Elliot (1969). For example, 1 kg of 5-g fish would use 64.2 mg more oxygen per hour than 1 kg of 15-g fish. Taking this into consideration, caution should be used in loading ponds with fish of different sizes. Available oxygen has to be a consideration in pond loading calculations. For example, in a raceway (8 x 80 x 3 feet) with an inflow of 1.07 cfs and 2.5 turn-overs per hour, with a dissolved oxygen level at the inflow of 9.0 mg/l and a minimum dissolved oxygen level at the outflow of 5.0 mg/l, there would be 544,372 mg of oxygen available for utilization. This pond could support 1741.0 kg of 15-g fish but only 1444.0 kg of 5-g fish. Relating this to Piper (1972), this pond could support a density of 0.553 lb/cu ft/inch of 5-g fish and only 0.465 lb/cu ft/inch of 15-g fish (based on a K-factor of

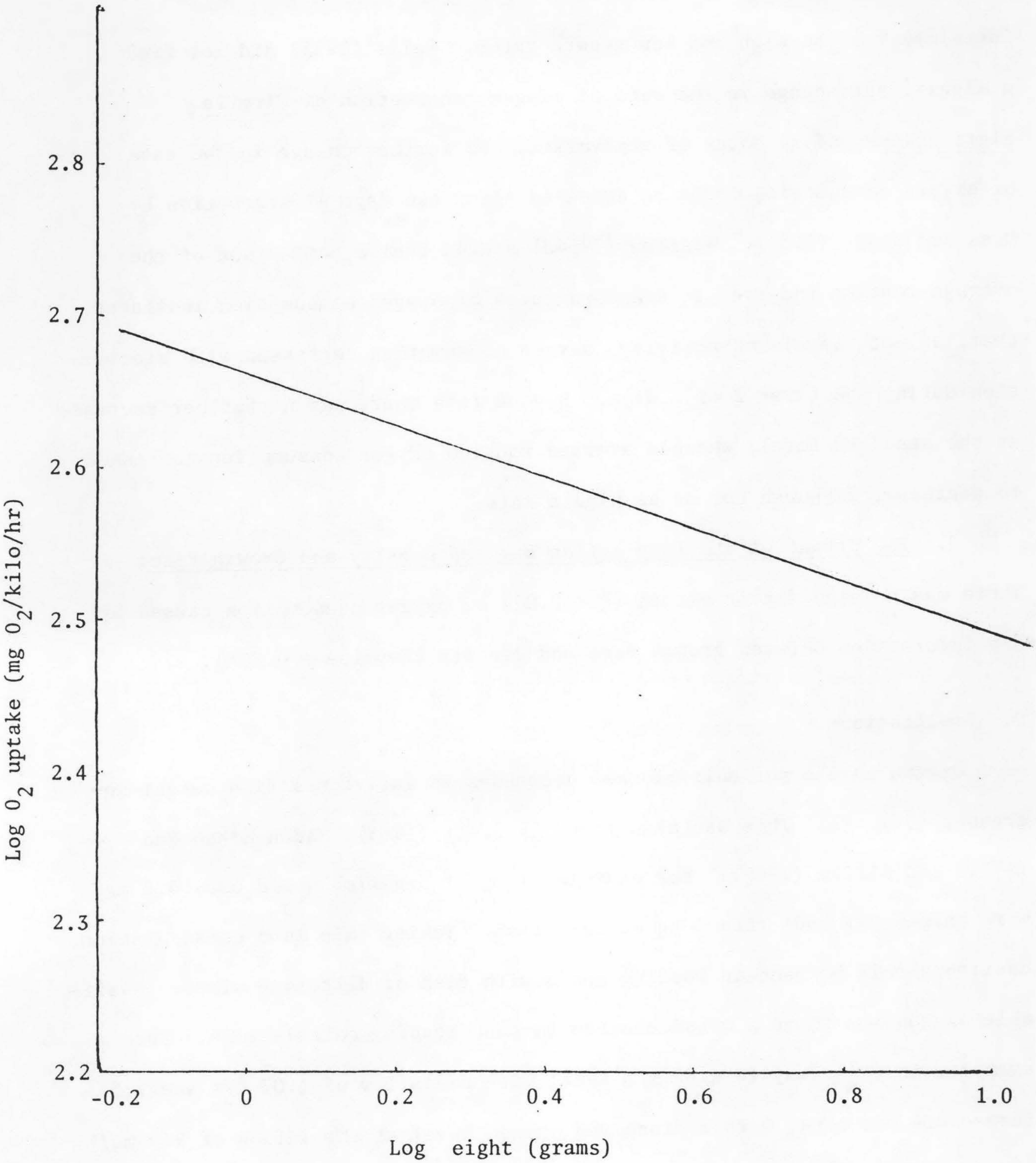

Fig. 7. Size-metabolism curve for the relation between oxygen uptake per kilogram regardless of density or feed rate (log Y = 2.695 + -0.17 log X).

of 0.00041). If the dissolved oxygen were dropped only 1 mg/l, it would drop the life support in the pond to a level that would only support 0.415 lb/cu ft/inch of 5-g fish and 0.349 lb/cu ft/inch of 15-g fish.

E. Conclusions

1. There is no significant effect ($P < 0.01$) on the rate of oxygen uptake between densities of 0.2 and 0.5 lb/cu ft/inch of body length.

2. Rainbow trout held in 59^{o}F water and starved for 20 to 22 hours prior to testing for oxygen consumption show no significant difference ($P < 0.01$) in rate of oxygen consumption caused by the difference between high ($\Delta L = 0.045$ inches) and low ($\Delta L = 0.035$ inches) growth rates.

3. The interaction between growth rate and density causes no significant change ($P < 0.01$) in the rate of oxygen consumption.

4. Per unit biomass, smaller fish use more oxygen than do larger fish.

5. Metabolic rate is reduced to the same baseline after 20 to 22 hours of starvation whether the fish were on a high or low growth rate program.

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VII. EVALUATION OF GROWTH DATA: A METHOD

A. Background

Any hatcheryman who has dealt with pond inventory records knows, firsthand, the frustration of not knowing exactly the numbers of fish or the total weight of fish in a pond. Most will agree that a $\pm$ 5% discrepancy between what is in the pond and what is on the record would be nice; but the discrepancy is often $\pm$ 15 to 20%. As it turns out, the results of this study improved somewhat on the error; but the error is still there and must be dealt with, since the over-all predictability and output are affected by the error.

The data used to evaluate growth rates were obtained from raising groups of rainbow trout in four 90-cu ft concrete tanks. Two groups were designated as the S-series, one of which was designated as S-A and the other S-B. Two groups were designated as the L-series, one of which was designated as L-A and the other L-B. The "S" designated small fish and the "L" designated large fish. The "A" designated one diet and "B" another diet, both commercially available. During the four biweekly growth periods the S-A group was fed diets A-3 and A-4, (numbers indicate pellet sizes). The S-B group was fed diets B-2 and B-3. The L-A group was fed diets A-5 and A-6. The L-B group was fed diets B-4 and B-5. All groups were fed at a level sufficient to increase the length during each 14-day period by 0.56 inches (1.422 cm). The feed conversions expected were 1.2 for diets A-3, A-4, B-2 and B-3; 1.5 for diets A-5, A-6, B-4 and B-5. The water $59^{\circ}F$ flows were adjusted to two change-overs per hour. The OWRT feeding program was used throughout the four growth periods. Initial and biweekly inventories were accomplished as follows:

1. Initial and subsequent pound-counts (no/lb) and individual lengths (mm) at the end of each growth period were taken by "herding" the fish

to the inflow end of the tank with a large dip net and removing each sample from the middle of the group (Tables 9 and 10).

2. Weights of biomass (lbs) were done initially and at the beginning of each growth period. The starting biomass in each growth period was done by the weight-in method rather than the weight-out method; i.e., fish were weighed into a pond rather than removing a calculated weight from the pond. Thus, the actual weight at the start of each growth period was known.

3. The biweekly data were recorded on a summary form especially designed for this study (Fig. 8) and transferred to a data compilation form (Table 11) for analysis.

B. Results and Discussion

Upon reviewing the compiled data (Table 11) we found that the age-old problem of discrepancy between estimated and actual numbers of fish and total biomass was present. Column 13 indicates that there is an 8.8% to -9.9% population difference between weights calculated from initial pound-counts and weights calculated from ending pound-counts. The net difference for the four growth periods for each group ranged from -2.99% to -17.32%. The comparisons between the total estimated weight gain (Col. 4 minus Col. 3) and the actual total weight gain during the four periods are less dramatic - i.e., -2.28% to -6.85%. What is indicated by both comparisons - numbers and weight - is that sampling errors were significant.

If it is assumed that 1) the pound-counts are accurate, 2) the mortalities are accurate, and 3) the actual weights are accurate, then the head-counts are accurate. But, the pound-counts at the end of each period multiplied by the weight at the end of each period does not equal the estimated head-count

Table 9. Sample sizes of S-series rainbow trout on 2 diets.

Period	No. measured	Sample Wgt.	No samples
Initial	44	200-400 g	5
1	44	200-400 g	4
2	44	1 lb	4
3	44	1 lb	5
4	44	2 lbs	4

Table 10. Sample sizes of L-series rainbow trout on 2 diets.

Period	No. measured	Sample Wgt.	No samples
Initial	22	1 lb	5
1	22	1 lb	5
2	44	1 lb	5
3	44	2 lbs	5
4	44	2 lbs	5

Fig. 8. Biweekly data recording form.

BIWEEKLY POND SUMMARY

Pond No. _______ Sample Date _______

Lot No. ________ Date of Last Sample ________

1. Number/lb at start		16. Growth	
2. Number/lb at end		17. Number of days	
3. Number/lb gain		18. Growth/day	
4. Number at start		19. Flow (gpm)	
5. Loss		20. Velocity (ft/sec)	
6. Number at end		21. Pounds/gallon/min.	
7. Weight at start		22. Pond Loading Index (lbs/pond/in)	
8. Weight at end		23. Pounds cubic foot	
9. Gain		24. Maximum Density Index (lbs/pond/in)	
10. Food fed		25. Temp (°C)	
11. Conversion		26. Temp units/inch	
12. Cost of food (¢/lb)		27. Oxygen (mg/l)	
13. Cost of fish/lb gain		28. K-factor (x 10^{-4})	
14. Length at end (mm)		29. Pond Constant - estimated	
15. Length at start (mm)		- actual	

Table 11. Biweekly inventory data from each of two size groups of rainbow trout split into two diet groups.

Parameter	No./lb.		Weight (lb.)					Population (nos.)					
Column	1	2	3	4	5	6	7	8	9	10	11	12	13
Calc. Method	Start Direct	End Direct	Start Direct	End_{calc} (10÷2)	$Gain_{calc}$ (4-3)	End Direct	Gain (6-3)	Start (1x3)	Morts Direct	End (8-9)	End_{calc} (2x6)	Diff. (11-10)	% (12÷10)
Size-Diet-Period													
Small A-1	583.43	365.63	22.36	35.45	13.09	38.60	16.24	13,047	85	12,962	14,114	+1152	+ 8.89
2	365.92	223.00	21.37	34.96	13.59	31.50	10.13	7,818	21	7,797	7,025	- 772	- 9.90
3	223.11	131.20	27.66	46.95	19.29	42.90	15.24	6,172	12	6,160	5,629	- 531	- 8.62
4	131.06	91.75	32.07	45.77	13.70	48.80	16.73	4,203	4	4,199	4,478	+ 279	+ 6.64
Small B-1	583.43	333.28	22.36	38.92	16.56	40.40	18.04	13,047	76	12,971	13,465	+ 494	+ 3.71
2	333.73	193.75	22.17	38.12	15.95	34.40	12.23	7,398	12	7,386	6,665	- 721	- 9.76
3	193.94	116.64	27.78	46.29	18.51	46.00	18.22	5,387	8	5,397	5,364	- 33	- 0.61
4	116.64	76.40	33.41	50.92	17.51	50.60	17.19	3,896	6	3,890	3,866	- 24	- 0.62
Large A-1	94.71	75.01	29.82	37.50	7.68	35.30	5.48	2,824	12	2,812	2,648	- 164	- 5.83
2	74.98	60.06	34.50	41.90	7.40	41.40	6.90	2,587	92	2,495	2,484	- 11	- 0.44
3	60.06	43.00	30.65	42.50	11.85	36.60	5.95	1,841	14	1,827	1,574	- 253	-13.85
4	43.00	33.50	33.68	42.70	9.02	43.90	10.22	1,448	17	1,431	1,471	+ 40	+ 2.80
Large B-1	94.71	70.81	29.82	39.73	9.91	38.10	8.28	2,824	11	2,813	2,697	- 116	- 4.12
2	70.81	45.80	36.13	54.96	18.83	48.90	12.77	2,588	41	2,517	2,240	- 277	-11.01
3	45.86	35.77	31.60	40.02	8.42	41.90	10.30	1,447	14	1,433	1,500	+ 67	+ 4.68
4	35.77	26.00	36.82	50.23	13.41	52.80	15.98	1,317	11	1,306	1,373	+ 67	+ 5.13

(Col. 10 vs. Col. 11); nor does the head-count at the end of the period (Col. 10) divided by the pound-count at the end of the period equal the actual weight at the end of the period (Col. 4 vs. Col. 6). Therefore, 1) the pound-counts are in error and the weights are correct, 2) the weights are in error and the pound-counts are correct, or 3) both the weights and the pounds are in error.

Some insight into the foregoing deductive logic was accomplished by ordering the lengths (mm) of sampled fish and determining the range, mid-range, median and mean for each sample (Table 12). Assuming a normal symmetrical distribution of lengths within a population, there would be similarity among the mid-range, median and mean lengths. Tests of this assumption indicated that 88.9% of the fish measured would fall within 95% of equality in their respective groups and that 100% of the fish would fall within 93.8% of equality. Thus, there were sampling biases in each inventory but within each group they tended to be mutually exclusive during the four growth periods.

In addition, the greater the length range the more likely the sample would be size selective, and thus the larger the pound-count bias. The following are methods of correcting the pound-counts to remove the sampling bias:

1. Corrected no/lb = (mean/mid-range) x no/lb_{obs}

   (Assumes a symmetrical distribution of length in the initial population.)

2. Corrected no/lb = $\left(\frac{\%\ \text{inequality}_{end}}{\%\ \text{inequality}_{start}} \times \%\ \text{inequality}_{end}\right) \times \text{no/lb}_{end}$

   (Assumes an asymmetrical distribution of length in the initial population which is treated as unity with respect to % equality of mean, median and mid-range.)

3. Corrected no/lb = no/lb off K-factor (0.0004) table using, length (mm) as the input.

   (Assumes that the length-weight comparisons within the sample were biased by the distribution of length within the sample.)

Table 12. Length sampling data of rainbow trout on programmed growth.

Period	n	Length: Range (mm)	Mid-range (mm)	Median (mm)	Mean (mm)	No./lb
S-A-0	44	19	39.5	43	42.1	583.4
1	44	19	48.5	50	49.9	365.9
2	44	23	59.5	60	60.3	223.
3	44	24	67	67	67.27	131.0
4	44	50	75	77.5	76.5	91.75
S-B-0	44	19	39.5	43	42.1	583.4
1	44	23	51.5	51.5	51.3	333.7
2	44	19	58.5	60	60.3	193.9
3	44	28	71	69	69.5	116.6
4	44	30	80	80	80.1	76.4
L-A-0	22	36	73	70.5	73.4	94.7
1	22	44	81	83.5	81.9	74.9
2	44	34	91	90	91.45	60.0
3	44	65	97.5	95	95.9	43.0
4	44	65	97.5	103.5	102.5	33.5
L-B-0	22	36	73	70.5	73.4	94.7
1	22	30	85	85	84.9	70.8
2	44	54	96	92	91.5	45.9
3	44	66	109	101.5	103.1	35.8
4	44	80	122	116.5	117.2	26.0

After applying each correction method to the data (Table 11), it was concluded that none would suffice to diminish the disparity already present. Method 2 did diminish the net error in the four growth periods in each group; however, the biweekly error was still quite significant.

From this study, the following recommendations may be made (but remain to be tested):

1. Determine the length (mm) frequency, distribution, range, mid-range, mean and median at each sampling. Unity of the mean and median is more significant than unity among mean, median and mid-range because mid-range values are from two extremes.

2. Crowd the fish to one end of the pond with a screen rather than "herding" them with a net. This will minimize the size selection bias.

3. Grade the fish when the length range exceeds 50% of the length range of the previous period. After grading, a new length distribution and pound-counts must be done.

4. Weigh the fish into the pond rather than removing a certain weight to reduce the biomass to the prescribed level.

5. Determine the biomass (weigh all fish) at the end of every second growth period.

6. For sample weighing small fish (1.5-3 inches) use a metric beam balance rather than an avoirdupois spring scale. Also, at each sampling, the balance or scale should be calibrated using at least three reference weights covering the range of the samples to be weighed. Samples of small fish should be weighed to the nearest 0.5 g (0.0011 lb), 3 to 6 inch fish samples should be weighed to the nearest gram (0.0022 lb), and samples of fish more than 6 inches should be weighed to the nearest 10 g (0.022 lb). Recall that 1 oz. equals 28.5 g; thus, if a one pound sample

were weighed to the nearest ounce the error will be 6.3%, while the error for weighing to the nearest 10 g will be 2.2%.

7. In sampling fish for no/lb estimates, a minimum of five samples should be weighed and counted. Each sample should contain 150 to 250 fish. There should be at least 90% agreement among the individual pound-counts. The most accurate pound-count will be obtained by dividing the total fish counted by the total weight, rather than by calculating the mean no/lb from each pound-count.

VIII. EFFECTS OF POPULATION DENSITY AND WATER REPLACEMENT TIME ON GROWTH: A STUDY

A. Background

As has been stated previously, there are many factors in an aquaculture system which can affect growth. This portion of the study was designed to test a method of determining the optimum biomass in a system permitting growth to occur without being affected by either population density or water replacement time.

The method, designated the Pond Loading Index (PLI), was derived by applying Piper's F (lbs of fish per gpm per inch body length) to Westers' method for carrying capacity (cf Appendix I). Piper's Flow Index method considers carrying capacity from the standpoint of water inflow and does not consider the volume of rearing space. It was assumed that F was fairly accurate, although it was derived empirically from a single value - namely, 1.5 lbs/gpm/inch. This value was found to permit good growth of fish in 50^{o}F water at an elevation of 5000 ft above mean sea level (MSL). A table of F-values (Table 13), taking into account the effect of temperature on metabolic rate and the effect of elevation and temperature on the dissolved oxygen level in water, assumed that 1) for each ^{o}F increase from 50^{o}F there would be a 4% increase in growth rate and carrying capacity, 2) for each ^{o}F decrease from 50^{o}F there would be a 5% decrease in growth rate and carrying capacity, and 3) for each 1000 ft decrease in elevation there would be a 4% increase in carrying capacity due to the additional dissolved oxygen (Piper 1970).

Westers' Water Replacement Time method considers carrying capacity as a function of water replacements per hour and volume of rearing space. However, Westers' method of determining the baseline pounds of fish by size groups is subject to some error in that it must be read from a graph (Westers 1970).

In the PLI method the maximum permissible pounds of fish per pond may be calculated by the following formula:

$$W_p = W_i \times V \times L \times R_\Delta$$

where W_p = lbs fish at length L per pond,

W_i = lbs fish per cu ft space per inch body length per water replacement per hour,

V = cubic feet of rearing space,

L = length of fish (inches) at the end of the growth period,

R_Δ = water changes per hour, determined by $\frac{8 \times gpm}{V}$

In this study, the PLI was used to represent the pounds of fish per inch of body length which the pond would support. It was then a simple matter to multiply the starting and ending lengths by the PLI to determine the starting and ending pond loadings.

The central figure in the PLI method is the pounds of fish per cubic foot of rearing space per water turn-over per hour per inch of body length (W_i). This figure can be expressed as the density index (DI) divided by the water changes per hour (R_Δ). The DI concept, developed by Piper (1972), has as its basis the fact that fish have an upper limit of crowding above which growth will be negatively affected. The DI equals the lbs of fish per cu ft per inch of body length. The following DI values were derived empirically:

1. rainbow trout 0.5
2. cutthroat trout 0.3
3. chinook salmon 0.3
4. coho salmon 0.4

Thus, the W_i serves another useful function by allowing a hatcheryman to determine the amount of water needed to maintain fish at a specified density.

Table 13. Load factors (Piper's F) in lbs fish/inch of length/gpm for trout and salmon as related to water temperature and elevation.

Water temperature °F	Elevation (ft above mean sea level)					
	0	1000	2000	3000	4000	5000
40	2.70	2.61	2.52	2.43	2.34	2.25
41	2.61	2.52	2.44	2.35	2.26	2.18
42	2.52	2.44	2.35	2.27	2.18	2.10
43	2.43	2.35	2.27	2.19	2.11	2.03
44	2.34	2.26	2.18	2.11	2.03	1.95
45	2.25	2.18	2.10	2.03	1.95	1.88
46	2.16	2.09	2.02	1.94	1.87	1.80
47	2.07	2.00	1.93	1.86	1.79	1.73
48	1.98	1.91	1.85	1.78	1.72	1.65
49	1.89	1.83	1.76	1.70	1.64	1.58
50	1.80	1.74	1.68	1.62	1.56	1.50
51	1.73	1.67	1.62	1.56	1.50	1.44
52	1.67	1.61	1.56	1.50	1.44	1.39
53	1.61	1.55	1.50	1.45	1.39	1.34
54	1.55	1.50	1.45	1.40	1.34	1.29
55	1.50	1.45	1.40	1.35	1.30	1.25
56	1.45	1.40	1.35	1.31	1.26	1.21
57	1.41	1.36	1.31	1.27	1.22	1.17
58	1.36	1.32	1.27	1.23	1.18	1.14
59	1.32	1.28	1.24	1.19	1.15	1.10
60	1.29	1.24	1.20	1.16	1.11	1.07
61	1.25	1.21	1.17	1.13	1.08	1.04
62	1.22	1.18	1.14	1.09	1.05	1.01
63	1.18	1.14	1.11	1.07	1.03	0.99
64	1.15	1.12	1.08	1.04	1.00	0.96

From Piper, 1970

For example, a system has a W_i of 0.170 (Table 14) and the fish have a DI of 0.4; then the water changes per hour must exceed 2.35.

In using the PLI method it must be kept in mind that the pond is not loaded at that level. The initial loading must be back-calculated from the PLI load, taking into account growth rate. This is inherent in both the BROCK and IRV programs.

B. Study Approach

The test systems consisted of two 8-tank units arranged so that there were duplicates of fish sizes, water replacement levels, densities and growth rates (Table 15). All groups were fed the same diet. The OWRT program was used to predict feeding rates and maximum loading.

C. Results and Discussion

The data obtained after four 14-day growth periods indicate that growth, measured as a change in length, was somewhat retarded in the W_i = 0.154 groups and markedly retarded in the W_i = 0.385 groups when compared with the W_i = 0.062 groups (Table 16). The difference between the mean growths of the two W_i = 0.154 groups is explained by the fact that the 1.3 water turn-over groups had hyperplastic gill epithelia and reduced oxygen uptakes. Presumably this was due to the accumulation of waste products. The gill tissues in the 3.25 water turn-over groups were unaffected and the oxygen uptakes were within prescribed limits (cf Section VI).

It was assumed from the data (Table 17) that if W_i = 0.062 can be considered to permit the maximum (100%) growth without the constraints of either density or water turn-over and that at W_i = 0.154 growth is affected by both density and water turn-over, the highest W_i at which growth is not affected by density or water turn-over lies somewhere between 0.062 and 0.154. Attemps to validate

Table 14. Pounds of fish (W_i) per cubic foot of rearing space per inch of body length per water turn-over per hour.*

Temperature °F	Elevation (ft above mean sea level)				
	0	1000	2000	3000	4000
32	0.427	0.416	0.405	0.394	0.381
33	0.416	0.405	0.394	0.382	0.369
34	0.405	0.394	0.382	0.371	0.358
35	0.394	0.382	0.371	0.360	0.348
36	0.382	0.371	0.360	0.349	0.337
37	0.371	0.360	0.349	0.337	0.326
38	0.360	0.349	0.337	0.326	0.315
39	0.349	0.337	0.326	0.315	0.304
40	0.337	0.326	0.315	0.303	0.293
41	0.326	0.315	0.305	0.293	0.283
42	0.315	0.305	0.293	0.283	0.273
43	0.303	0.293	0.282	0.273	0.264
44	0.292	0.282	0.272	0.264	0.256
45	0.281	0.272	0.262	0.254	0.244
46	0.270	0.261	0.252	0.242	0.234
47	0.259	0.250	0.241	0.232	0.225
48	0.247	0.239	0.231	0.222	0.215
49	0.236	0.229	0.220	0.212	0.205
50	0.225	0.217	0.210	0.202	0.195
51	0.216	0.209	0.202	0.195	0.188
52	0.209	0.201	0.195	0.187	0.180
53	0.201	0.194	0.187	0.181	0.174
54	0.194	0.187	0.181	0.175	0.168
55	0.187	0.181	0.175	0.168	0.163
56	0.181	0.175	0.168	0.164	0.158
57	0.176	0.170	0.164	0.159	0.153
58	0.170	0.165	0.159	0.154	0.148
59	0.165	0.160	0.155	0.148	0.144
60	0.161	0.155	0.150	0.145	0.139

* Applicable to raceways only

Table 15. Program inputs to test effects of density and water replacement.

	Common to all Systems
Elevation	3000 ft above MSL
Water temperature	$59^{o}F$ ($15^{o}C$)
Volume	3.75 cu ft
DO* (in)	8.9 mg/1
DO (out)	6.0 mg/1
K-factor	4.0×10^{-4}

System	A' (initial weigh 0.387 g)		A (initial weight 4.340 g)	
Water flow (gpm)	0.609	1.523	0.609	1.523
Density (lb/cu ft/inch)	0.2	0.5	0.2	0.5
Fish L_o (inches)	1.305	1.305	2.866	2.866
ΔL (inches/day)	0.045	0.045	0.035	0.035
Diet efficiency (%)	83.3	83.3	66.7	66.7

Table 16. Growth (ΔL_t) of rainbow trout raised at two densities and at two water replacement times.

A' = initial weight 0.387 g; A = initial weight 4.340 g.

Parameter	A'-1	A'-2	A'-3	A'-4	A'-5	A'-6	A'-7	A'-8
DI (lb/cu ft/inch)	0.2	0.2	0.5	0.5	0.2	0.2	0.5	0.5
R_Δ (water changes/hr)	3.25	1.3	3.25	1.3	3.25	1.3	3.25	1.3
L_o (initial length)	1.305	1.305	1.305	1.305	1.305	1.305	1.305	1.305
Growth period (14 days)								
1	1.746	1.726	1.732	1.742	1.742	1.756	1.711	1.746
2	2.132	2.069	2.018	1.963	1.963	2.071	2.093	1.988
3	2.327	2.415	2.436	2.266	2.266	2.415	2.346	2.240
4	2.799	2.614	2.614	2.411	2.411	2.746	2.825	2.293
ΔL_t	1.494	1.327	1.309	1.106	1.106	1.441	1.502	0.988
$\frac{\Delta L_t}{L_o}$ (%)	114.5	101.7	100.3	84.8	128.5	110.4	116.5	75.7

Table 16. Continued.

Parameter	Group A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8
DI (lb/cu ft/inch)	0.2	0.2	0.5	0.5	0.2	0.2	0.5	0.5
R_Δ (water changes/hr)	3.25	1.3	3.25	1.3	3.25	1.3	3.25	1.3
L_o (initial length)	2.866	2.866	2.866	2.866	2.866	2.866	2.866	2.866
Growth period (14 days)								
1	3.059	3.089	3.071	2.933	3.240	3.175	3.079	2.980
2	3.364	3.382	3.287	3.112	3.510	3.344	3.258	3.157
3	3.876	3.628	3.719	3.163	3.945	3.880	3.732	3.266
4	3.982	3.821	3.913	3.293	4.343	4.167	4.152	3.423
ΔL_t	1.116	0.955	1.047	0.427	1.477	1.301	1.286	0.557
$\frac{\Delta L_t}{\Delta L_o}$ (%)	38.9	33.3	36.5	14.9	51.5	45.4	44.9	19.4

Table 17. Comparison of methods to estimate fish carrying capacity in systems having the constraints of density and water replacement (4 samples).

Parameter	Period 1 - A' System			
	1	2	3	4
R_Δ (water changes/hr)	3.25	1.3	3.25	1.3
DI (lb/cu ft/inch)	0.2	0.2	0.5	0.5
W_i $(\frac{DI}{R_\Delta})$	0.062	0.154	0.154	0.385
Carrying capacity (lb) (PLI Method)	1.4	1.5	3.6	3.6
Est. growth (inches)	2.52	2.52	2.52	2.52
Obs. growth (inches)	1.58	1.37	1.42	9.00
Obs./est. (%)	62.7	54.4	56.3	39.3
Calculated carrying capacity (lb) per				
Feed level method	2.1	0.8	2.1	0.8
Flow index method	3.4	1.4	3.4	1.4
Oxygen uptake method	4.0	1.6	4.0	1.6
Density factor method	1.4	1.4	3.6	3.6
Water replacement time method	1.5	0.6	1.5	0.6

this assumption by accurately locating the W_i permitting maximum growth without being affected by either density or water turn-over failed because of the insufficient number of data points to establish a meaningful slope. However, by comparing the data from all groups tested in this study, for whatever intent, a W_i of 0.144 appeared consistently to be the value sought. The W_i from the table (Table 14) is 0.148, or 2.8% over the W_i suggested by the data.

For comparison with other methods of determining permissible biomass in the study systems, the inputs for the first growth period in system A' (Table 15) were used. Assuming that the PLI method is valid, all other methods can be used safely. However, if density is a constraint, the biomass permitted using either the flow index method or the oxygen uptake method will require correction, as neither considers density. Also, if water turnover is a constraint, the biomass permitted using the density factor method will have to be corrected because it does not consider water inflow. Use of either the feed level method or the water replacement time method will permit safe loadings, though considerably under optimum, in the systems tested.

In summary, the PLI method offers the user the ability to consider fish length, water inflow and density in raceway systems. The table W_i is the relationship between density and water replacements per hour. If density is a constraint, then the water flow can be adjusted and vice versa. For example, if the table $W_i = 0.165$ and the optimum DI is 0.3, then the water replacements must exceed 1.82 per hour. Correspondingly, if only 1.4 water replacements per hour are available, the density cannot exceed 0.23 lb/cu ft/inch without growth being affected.

References Cited

Piper, R.G. 1970. Know the proper carrying capacities of your farm. American Fishes and U.S. Trout News 15(1):4.

Piper, Robert G. 1972. Managing hatcheries by the numbers. American Fishes and U.S. Trout News 17(3):10.

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IX. ESTIMATION OF SOLIDS GENERATED IN AN AQUACULTURE SYSTEM: A STUDY

A. Background

As was stated at the outset of this report, the discharge of waste products from aquaculture systems has come under the scrutiny of the Environmental Protection Agency. At the present time the average suspended solids load that can be discharged legally is 2.2 lbs per 100 lbs of fish per day. The maximum daily suspended solids load cannot exceed 3.3 lbs per 100 lbs of fish. The cleaning effluent cannot contain more than 2.2 ml/l settleable solids and the non-cleaning effluent cannot contain more than 0.2 ml/l settleable solids. Currently, large amounts of money and time are being spent in both the public and private sectors to seek economical and practical methods of compliance with the existing regulations. This study is part of those efforts.

This portion of the study was based on the belief that existing management methods were sufficient to maintain discharge quality within the regulated levels. Considerable time was spent identifying the qualitative and quantitative factors involved in waste product generation (cf Section III).

Throughout the process of factor identification, feed quality and quantity kept emerging as the most likely candidates for study. Feed quantity was considered to be dependent upon the desired growth rate and the dietary efficiency - i.e., feed quality. It was further considered that the hatcheryman had the ability to establish the growth rate within the constraints of the aquaculture system; however, we had no control over the dietary quality unless a diet of specified composition was fed.

There have been two methods of estimating the amount of solids generated daily in an aquaculture system. Both are based upon the feeding rate (lbs of feed per 100 lbs of fish) and do not take into account dietary efficiency. Willoughby, Larsen and Bowen (1972) proposed that by multiplying the lbs of feed fed per gpm by 25, one could estimate the mg/l solids generated. Converting mg/l to lbs/day can be accomplished in the following manner:

$$\text{lbs} = \frac{\text{mg/l x cfs}}{0.184}$$

Thus, the calculation becomes

$$\text{lbs solids per day} = \frac{\text{25 x lbs feed/gpm x cfs}}{0.184}$$

Liao and Mayo (1974) proposed that the suspended solids production rate (lbs/100 lbs fish/day) at 50-58^{o}F could be estimated by multiplying the feed rate (lbs feed/100 lbs fish/day) by 0.52.

In this study, we tested a new method of estimating lbs of solids generated per 100 lbs of fish per day that considered both dietary quality and quantity.

B. Study Approach

Data were gathered from applying methods described in Sections V, VI, VII and VIII. Each of these sections incorporated provisions for determining feed efficiencies as they relate to estimated growth rates. Daily solids production levels were recorded for varying conditions of population density, water replacement time, feeding rate and diet quality.

C. Results and Discussion

It became apparent at the outset of data analysis that dietary efficiency was a function of not only diet quality but also feeding rate, based upon estimated weight gain. The method used to estimate weight gain was based upon the ΔL concept, in which the daily increase in length is proportional to the cube root of the weight. Thus, if a group of 3-inch fish (uniform length) were to increase their length by 0.5 inch, the expected weight gain would be 58.7% of the starting weight. For a group of 5-inch fish, an increase of 0.5 inches would increase the weight by 32.9% of the starting weight. These estimations (Table 18) were taken from the weight-length tables (USFWS 1977) and are independent of K-factor.

Data from four lots of fish were selected (Table 19) to typify the situation. Lot A'-6-3 was fed to achieve a weight gain of 111.8% and Lot A'-2-3 was fed for an 81.5% weight gain. Both groups contained virtually the same length fish, with a length range of 20 mm. The weight gains during the 14-day period were 55.7% and 51.5%, respectively. It should be noted that the fish in both groups ate all the feed, with little or no wastage. A third group (Lot S-B11-4) consisting of fish of similar size but in greater numbers, was fed for a 68.1% weight gain and the actual gain was 51.6%. The maximum weight gains considered possible, based upon percent length increase under the circumstances, were 56.4%, 56.8% and 53.4%, respectively. A fourth group, (Lot L-B12-4) consisting of large fish (4 inches), was fed for a 43.6% weight gain and the actual gain was 43.5%, with the maximum gain for this size fish estimated to be 47.2%.

The following dietary efficiencies were recorded for the four groups:

% est. weight gain	% diet efficiency	conversion
111.8	40.1	1:2.49
81.5	50.8	1:1.97
68.1	55.9	1:1.79
43.6	64.5	1:1.55

Table 18. Percent weight increase (%ΔW) in relation to length increase (ΔL).

Length (inches)	%ΔW/0.25 inch ΔL	%ΔW/0.5 inch ΔL
1.0		
1.25	95.4	
1.5	73.1	238.2
1.75	58.4	
2.0	49.3	136.6
2.25	42.5	
2.5	37.1	95.3
2.75	33.8	
3.0	29.1	72.8
3.25	27.1	
3.5	24.8	58.7
3.75	23.1	
4.0	21.4	49.4
4.25	20.2	
4.5	18.9	42.9
4.75	17.3	
5.0	16.5	36.7
5.25	15.7	
5.5	14.9	32.9
5.75	14.2	
6.0	13.6	29.9
6.25	13.1	
6.5	12.6	27.3
6.75	11.9	
7.0	11.5	24.4
7.25	11.2	
7.5	10.9	23.6
7.75	10.5	
8.0	9.6	22.0
8.25	9.6	
8.5	9.3	19.8
8.75	9.1	
9.0	8.9	18.7
9.25	8.7	
9.5	8.5	18.1
9.75	7.9	
10.00	7.8	16.3

Table 19. Growth in four groups of rainbow trout fed at different rates beased on estimated weight gain.

Parameter	Lot			
	A'-6-3	A'-2-3	L-B12-4	S-B11-4
Diet	A-4	A-4	B-5	B-3
$\%\Delta W_{14}$ - expected	111.8	81.5	43.6	68.1
$\%\Delta W_{14}$ - observed	55.7	51.5	43.5	51.6
Max $\%\Delta W_{14}$	56.4	56.8	47.2	53.4
Length (inches) - start	2.071	2.069	4.059	2.733
Length (inches) - end	2.415	2.415	4.623	3.162
ΔL_{14} (inches) - observed	0.344	0.346	0.564	0.429
ΔL_{14} (inches) - expected	0.63	0.49	0.56	0.56
$\%\Delta L_{14}$ - observed	16.1	16.7	13.9	15.7
$\%\Delta L_{14}$ - expected	23.7	30.4	13.8	20.5
% Digestibility of:				
Protein	73.3	52.4	68.4	84.1
Fat	85.9	83.1	78.1	89.8
NFE	30.1	41.7	54.2	56.9
TDN	65.1	55.9	67.5	77.7
PER	9.97	0.77	1.11	1.36
Dietary efficiency	50.8	40.1	55.9	64.5

Thus, it can be seen that although the three groups of fish in the 2-inch size range were fed at different levels, all three grew at about the same rate, with the differences being seen in the diet efficiencies. This indicates that there were more waste products generated in the 111.8% weight gain group than in the 43.6% weight gain group.

By comparing proximate analyses of the collected feces with the proximate analyses of the diets, another facet of growth becomes apparent (Table 19). The protein utilization was highest in Lot L-B12-4 and lowest in Lot A'-6-3 - i.e., the lowest and highest estimated percent weight gains, respectively. These data are substantiated by the (protein efficiency ratio) (PER) values. However, fat utilization among all groups, regardless of feeding rate, was very similar. Carbohydrate utilization (expressed as NFE digestibility) appeared to vary independently from feeding rate. Among the several explanations for these observations, the only plausible one is that the high feeding rate fish (111.8% weight gain) were fed several times daily and the sheer bulk as compared with a lower feeding rate group decreased the time the ingesta resided in the digestive tract. Also, the intestinal tract was much more distended in the higher feeding rate group than in the lower feeding rate group, thereby decreasing the exposure of the ingesta to the intestinal lining. Both these factors contributed to the decreased overall efficiency. Apparently, fat is absorbed quite readily, while it takes more time and greater exposure to the intestinal lining to utilize crude protein efficiently. These assumptions are somewhat borne out in the TDN values.

From the foregoing observations and interpretations, it became obvious that a better method of estimating the weight gain during a growth period must be developed. It is accepted that small fish have a greater percent weight

weight gain per length increment increase than do larger fish. This can easily be visualized by comparing the weight/1000 fish gain with length increase using the standard length-weight tables. For example, fish under 1.5 inches will increase in weight 4.7% for each 1% length increase, while fish over 5.5 inches will increase their weight 3.4% for each 1% length increase (Table 20).

Table 20. W-factors for calculation of estimated % weight gain (multiply the % estimated length increase by the approximate W-factor).

Fish length (inches)	W-factor
<1.5	4.7
1.5 - 3.0	3.8
3.0 - 5.5	3.4
5.5 - 10	3.2

The 14-day length increase expected for a 4.2-inch fish is 0.4 inch or a 9.5% increase. The estimated weight increase will be 9.5 x 3.4 or 32.3%. Using the ΔL method, only a 28.6% weight increase can be expected for the same period. This suggests that the length-weight conversion factor of 3 in the ΔL equation should be replaced with the correct W-factor. In the example, the two methods would be equilibrated if this were done, thus eliminating the necessity of having to calculate the percent length increase and multiplying it by the W-factor. Back-calculating this concept into the data presented (Table 19) indicates a high degree of correlation.

Application of these assumptions, together with the weights of feces collected for each group, gave rise to a method of estimating the solids generated per 100 pounds (S_{100}) of fish per day. It states:

$$S_{100} = 0.95\ [\text{lbs fed} - (\text{lbs fed} \times \text{efficiency})] \times \text{cwt}$$

This method assumes that 95% of the metabolic waste will be as solids. This assumption is supported by the fecal sample data. Recalling that the feces were collected in fine mesh "socks", dried and weighed, an error in quantitative proximate analysis could have been introduced by the leaching of the solubles into the water. However, the leaching was considered to be of no consequence because this is what normally happens to fish feces.

The method has the advantage over the Willoughby method and the Liao method of considering the dietary efficiency. In two selected groups of fish, the following lbs of solids per 100 lbs of fish were calculated:

Lot L-A12-4-14 (the 14th day of the 4th period of Lot L-A-12)

Willoughby - 1.06

Liao - 2.24

Proposed - 2.34

Lot L-B12-4-14 (the 14th day of the 4th period of Lot L-B12)

Willoughby - 1.32

Liao - 2.38

Proposed - 1.55 (From Table 21)

Both groups consisted of essentially the same number of fish and the same size fish. Both were fed at comparable rates. The difference was in the respective dietary efficiencies. Lot L-A12 had a dietary efficiency of 41.3%, whereas lot L-B12 had a dietary efficiency of 64.1%. According to the Liao method both groups exceeded the EPA discharge limits and according to the Willoughby method neither exceeded the EPA discharge limits. According to the proposed method the lot with the lower dietary efficiency exceeded the discharge limits but the other did not.

A chart was constructed to estimate the lbs of solids generated per 100 lbs of feed based upon the dietary efficiency (Table 22). It is very simple to visualize the importance of having the dietary efficiency as high as possible. For example, 300 lbs of feed being fed daily to 10,000 lbs of fish will generate 1.07 lbs solids per 100 lbs of fish at a dietary efficiency of 62.5%. However, at a dietary efficiency of 50%, 1.43 lbs of solids per 100 lbs of fish will be generated.

In summary, we think that more basic and applied research must be done to "fine tune" the method used. At best estimate, based upon the data collected, there is no more than a 5% error between the actual values and the calculated values. Furthermore, we think a large portion of the error to consist of the usual rounding errors encountered whenever numerical significance is attempted.

References Cited

Liao, P.B., and R.D. Mayo. 1974. Intensified fish culture combining water reconditioning with pollution abatement. Aquaculture 3:61.

U.S. Fish and Wildlife Service, USDI. 1977. Manual of Fish Culture. Appendices 1.5-5.0 - English and metric length-weight relationships for fish.

Willoughby, H., N. Larsen and J.T. Bowen. 1972. The pollutional effects of fish hatcheries. American Fishes and U.S. Trout News 17(3):6.

Table 2 1. Two examples of estimation of solids (lbs) produced daily in two groups of rainbow trout using three methods.

<u>Example 1:</u>

Unit - L-A12-4-14

Biomass - 49.6 lbs (22.518 kg)

Feed - 2.08 lbs (944.32 g)

Feeding Rate - 4.3%

Dietary Efficiency - 0.413

Water - 28.1 gpm (0.0624 cfs)

Willoughby's Method:

$$\text{Solids} = \frac{25 \times \text{lbs feed/gpm} \times \text{cfs}}{0.184}$$

= 0.593 lb

= 1.106 lbs/100 lbs fish

Liao's Method:

$$\text{Solids} = 0.52 \times \text{feed rate} \times \text{lbs fish} \times 10^{-2}$$

= 1.11 lbs

= 2.24 lbs/100 lbs fish

Proposed Method:

$$\text{Solids} = 0.95 \left[\text{lbs feed} - (\text{lbs fed} \times \text{effic.})\right]$$

= 1.16 lbs

= 2.34 lbs/100 lbs fish

Table 21. Continued.

<u>Example 2</u>:

Unit - L-B 12-4-14

Biomass - 52.86 lbs (23.998 kg)

Feed - 2.42 lbs (1.098 kg)

Feeding rate - 4.58%

Dietary Efficiency - 0.641

Water - 17.97 gpm (0.0399 cfs)

Willoughby's Method:

$$\text{Solids} = \frac{25 \text{ x lbs feed/gpm x cfs}}{0.184}$$

= 0.70 lbs

= 1.32 lbs/100 lbs fish

Liao's Method:

$$\text{Solids} = 0.52 \text{ x feed rate x lbs fish x } 10^{-2}$$

= 1.26 lbs

= 2.38 lbs/100 lbs fish

Proposed Method:

Solids = 0.95 [lbs feed - (lbs fed x effic.)]

= 0.82 lbs

= 1.55 lbs/100 lbs fish

Table 22. Estimated* lbs solids/100 lbs feed as related to dietary efficiency.

Feed conversion	Dietary efficiency (%)	Lbs solids/ 100 lb feed
1.1	90.9	8.65
1.2	83.3	15.87
1.3	76.9	21.95
1.4	71.4	27.17
1.5	66.7	31.64
1.6	62.5	35.63
1.7	58.8	39.14
1.8	55.6	42.18
1.9	52.6	45.03
2.0	50.0	47.50
2.1	47.6	49.78
2.2	45.5	51.78
2.3	43.5	53.68
2.4	41.7	55.39
2.5	40.0	57.00

* Solids (lbs) = 0.95 [lbs fed - (lbs fed x diet effic.)]

X. SUMMARY

As was stated at the outset of this report, the objectives of this study were to develop and test methods of predicting waste product generation from aquaculture facilities. The approach to attain the objectives began with a complete identification of the factors involved in waste product generation. It was found that, among the 40-plus factors having the capability of affecting production in an aquaculture facility, each factor interacted with one or more other factors in a dependent or counterdependent manner. The problem of selecting those factors having the greatest role in waste product generation and also having the greatest potential for being controlled through management techniques was resolved after considerable consultation with professional fish culturists, both public and private, and testing opionons in a model flow chart.

The factors chosen for testing were 1) feeding rate; 2) diet efficiency, 3) growth rate, 4) population density, 5) water replacement time, 6) oxygen consumption, 7) fish size, and 8) water temperature. Although there were other probable choices for consideration, we believed the eight chosen were at "the top of the heap", with the other factors being dependent functions (cf Section II).

We believe the following to be significant results of the study:

1. The identification of factors not only involved with the generation of waste products from an aquaculture facility, but also having the potential of affecting the production of an aquaculture facility.

2. The development of a practical method for determining oxygen consumption of fish in varying controlled environmental conditions.

3. The development of a computerized program for fish growth in optimized loading conditions of population density and water replacement time.

4. The development of a method to predict more accurately the anticipated growth rate of a group of fish, which corrects the existing method.

5. The development of a method to predict the solids, both settleable and suspended, produced daily by a group of fish being held in known conditions.

Although it is conceded that more research must be done, this study clearly indicates that it is within the capability of existing fish culture technology to control waste product discharge from fish-raising facilities through management, so as to comply with the current EPA regulations. Sophisticated and expensive pond-cleaning equipment and solids disposal methods should be necessary only in those cases where continously cleaning ponds do not exist or pond cannot be modified to be so.

In conclusion, we would like to suggest the following topics for future research to further understand the fish:water:nutrition:container:management interrelationships:

1. The effect of dietary quality on survival of game fish following release from the hatchery environment.

2. The testing of the fish:container relationships with respect to hydraulic action of the pond, fish behavior, self-cleaning propensities, and pond shape and dimensions.

3. The effect of regularly scheduled continuing education sessions for fish culturists and fishery resource managers.

APPENDIX I

Published Carrying Capacity Methods

A. Feeding Level Method (Haskell 1955)

$$\text{Lbs fish/cu ft} = \frac{\text{max. lbs feed per cu ft x 100}}{\text{percent body weight fed}}$$

B. Feeding Level Method (Willoughby 1968)

$$W_n = \frac{N}{R_f \times 10^{-2}}$$

Where W_n = total weight of fish in pond (lbs),

N = pounds of food per day,

$= (0_a - 0_b) \times \frac{5.45}{100} \times R_w$

0_a = ppm dissolved oxygen incoming,

0_b = ppm dissolved oxygen at outfall (min. 5 ppm for salmonids),

5.45 = metric tons of water at 1 gpm for 24 hours,

100 = grams oxygen required to metabolize 1200 kcal,

R_w = water inflow in gpm,

R_f = feeding rate in percent body weight of fish

$= \frac{\text{conversion factor} \times \Delta L \times 3 \times 100}{L}$

conversion factor = pounds of feed required per lb of body weight gain,

ΔL = daily increment of length increase inches,

3 = weight-length conversion factor.

C. Water Replacement Time Method (Westers 1970)

$$\text{Lbs fish/cu ft} = \frac{\text{lbs fish/gpm x no. water changes/hr}}{8}$$

$$W_t = \frac{(W_{gpm} \times R_{\Delta}) \times V}{8}$$

where W_t = pounds of fish in pond,

W_{gpm} = pounds of fish/gpm,

R_{Δ} = water changes/hr,

8 = conversion of gpm to cfh,

V = pond volume (cu ft).

D. Oxygen Uptake Method (Elliott 1969)

$$W = \frac{0_i - 0_o}{Y_n}$$

where W = pounds of fish per gpm,

Y = oxygen requirement for fish at size 'n'

= a x T - b

(a & b are constants, T is ^oF),

0_i = dissolved oxygen (mg/l) inflow,

0_o = dissolved oxygen (mg/l) outflow.

F. Oxygen Consumption Method (Liao 1971)

$$W_o = \frac{R_w \times 1.2\,(C_e - C)}{K \times T^n \times W^m}$$

where W_o = weight of fish in pond (lbs),

R_w = water inflow (gpm),

1.2 = correction constant,

C_e = dissolved oxygen (ppm) at temperature T (^oF), elevation E and saturation S,

$$= \frac{S \times 132}{T^{0.625}} \times \frac{760}{\frac{760 + E}{32.8}}$$

C = minimum dissolved oxygen at outfall,

K = rate constant

salmon	$<50^oF$	7.20×10^{-7}
	$>50^oF$	4.90×10^{-5}
trout	$<50^oF$	1.90×10^{-6}
	$>50^oF$	3.05×10^{-4}

T = water temperature (^oF),

n = temperature-water slope,

salmon	$<50^oF$	3.200
	$>50^oF$	2.120
	$<50^oF$	3.130
	$>50^oF$	1.855

W = weight of individual fish (lb),

m = weight-oxygen slope.

salmon	$<50^oF$	-0.194
	$>50^oF$	-0.194
	$<50^oF$	-0.138
	$>50^oF$	-0.138

G. Density Factor Method (Piper 1972)

$$W_d = D \times V \times L$$

where W_d = total weight of fish in pond (lbs),

D = density factor (lbs fish/cu ft/inch fish length),

V = volume of rearing space in pond (cu ft),

L = length of fish (inches).

Table 1A. Load factors (lbs fish/inch of length/gpm) for trout and salmon as related to water temperature and elevation.

Water Temperature (°F)	Elevation (ft above mean sea level)					
	0	1000	2000	3000	4000	5000
40	2.70	2.61	2.52	2.43	2.34	2.25
41	2.61	2.52	2.44	2.35	2.26	2.18
42	2.52	2.44	2.35	2.27	2.18	2.10
43	2.43	2.35	2.27	2.19	2.11	2.03
44	2.34	2.26	2.18	2.11	2.03	1.95
45	2.25	2.18	2.10	2.03	1.95	1.88
46	2.16	2.09	2.02	1.93	1.87	1.80
47	2.07	2.00	1.93	1.86	1.79	1.73
48	1.98	1.91	1.85	1.78	1.72	1.65
49	1.89	1.83	1.76	1.70	1.64	1.58
50	1.80	1.74	1.68	1.62	1.56	1.50
51	1.73	1.67	1.62	1.56	1.50	1.44
52	1.67	1.61	1.56	1.50	1.44	1.39
53	1.61	1.55	1.50	1.45	1.39	1.34
54	1.55	1.50	1.45	1.40	1.34	1.29
55	1.50	1.45	1.40	1.35	1.30	1.25
56	1.45	1.40	1.35	1.31	1.26	1.21
57	1.41	1.36	1.31	1.27	1.22	1.17
58	1.36	1.32	1.27	1.23	1.18	1.14
59	1.32	1.28	1.24	1.19	1.15	1.10
60	1.29	1.24	1.20	1.16	1.11	1.07
61	1.25	1.21	1.17	1.13	1.08	1.04
62	1.22	1.18	1.14	1.09	1.05	1.01
63	1.18	1.14	1.11	1.07	1.03	0.99
64	1.15	1.12	1.08	1.04	1.00	0.96

APPENDIX II

List of OWRT Fish Culture Program

OWRT

```
10 WRITE(6,10)
20 10 FORMAT(3X,'TYPE IN THE NUMBER OF TANKS AND NO. OF PERIODS TO BE RUN -
EXAMPLE ?3,1')
30 READ(5,*)JJ,MM
40 DO 123 J=1,JJ
50 WRITE(6,1)
60 1 FORMAT(3X,'TYPE IN ROOM NUMBER AND TANK NUMBER (8 SPACES MUST BE FILLED)
EX. ?112,  5A')
70 READ(5,23)A,AA
80 23 FORMAT(2A4)
90 WRITE(6,33)
100 33 FORMAT(2X,'TYPE IN DELTAL,MAX. DENSITY INDEX,POND CHANGES(RDELTA),PLI
NO.,% DAILY MORTALITY')
110 READ(5,*)DELTAL,DI,RDELTA,PLIALT,PCMORT
120 WRITE(6,25)
131 25 FORMAT(1X,'TPE IN LENGTH,NO./LB.,K-FACTOR,POND VOLUME,EST. CONVERSION,
WATER TEMP.')
140 READ(5,*)ZLONG,ZN(LB,ZKFACT,VOL,ESTCON,TEMP
150 WRITE(6,26)A,AA
160 26 FORMAT(20X,'ROOM NUMBER",A4,3X,'TANK NUMBER',A4)
170 WRITE(6,2)DELTAL,TEMP
180 2 FORMAT(1X,' DELTAL =    ',F6.4,30X,' TEMPERATURE =    ',F5.0/)
190 WRITE(6,3)ESTCON,RDELTA
200 3 FORMAT(1X,'EST. CONVERSION = ',F5.3,27X,'POND CHANGES/HOUR = ',F5.3/)
210 WRITE(6,4)ZLONG,ZNOLB
220 4 FORMAT(1X,'STARTING FISH LENGTH = ',F6.4,21X,'#/LB - ',F10.3/)
230 WRITE(6,6)VOL,DI
240 6 FORMAT(1X,'POND VOLUME = ',F9.3,30X,'DENSITY INDEX = ',F5.3/)
242 WRITE(6,7)ZKFACT,PCMORT
244 7 FORMAT(1X,'K-FACTOR = ',F8.6,30X,' % DAILY MORTALITY - ',F5.3/)
250 DO 180 M=1,MM
260 WRITE(6,11)
270 11 FORMAT(1X,/' DAY  POND WEIGHT NO.?LB  LENGTH   % BW FED  FEED  NO. FISH')
280 ZLONG=ZLONG+DELTAL*13
290 ZMDI=DI*VOL*ZLONG
300 ANOLB=1./(ZKFACT*ZLONG**3)
310 ZNUMB=ZMDI*ZNOLB/((1.-PCMORT/100.)**13)
315 DAY14=(ZNUMB/ZNOLB)*(ESTCON*3*DELTAL)/ZLONG
320 ZLONG=ZLONG-DELTAL*13.
330 FEDSUM=0.
340 DO 111 I=1,14
342 IF(I .GT. 7) GO TO 99
344 XDAY14=.05*DAY14*454
345 GO TO 17
346 99 XDAY14=.093*DAY14*454
348 17 CONTINUE
350 AMDI=DI*VOL*ZLONG
360 ZNOLB=1./(ZKFACT*ZLONG**3)
380 MORTS=ZNUMB*(PCMORT/100.)
390 TOTWT=ZNUMB/ZNOLB
```

```
PLI=PLIALT*VOL*ZLONG*RDELTA
PCBDWT=(ESTCON*300.*DELTAL)/ZLONG
FOODFD=(TOTWT*PCBDWT/100.)*454.+XDAY14
IF(I .EQ. 14) FOODFD=0.
FEDSUM=FEDSUM+FOODFD
IF(M .EQ. 1) GO TO 100
IF(I .NE. 1) GO TO 100
DIFFWT=ZMMDI-TOTWT
DIFNUM=ZNNUMB-ZNUMB
WRITE(6,5)DIFFWT,DIFNUM
5 FORMAT(1X,'REMOVE ',F10.3,'POUNDS OR ',F10.0,'FISH'/)
100 WRITE(6,15)I,TOTWT,ZNOLB,ZLONG,PCBDWT,FOODFD,ZNUMB
15 FORMAT(I5,F12.2,F8.2,3F10.2,F10.0,/)
ZLONG=ZLONG+DELTAL
ZNUMB=ZNUMB-MORTS
ZMMDI=ZMDI
ZNNUMB=ZNUMB+MORTS
111 CONTINUE
WRITE(6,112) FEDSUM
112 FORMAT(1X,' TOTAL FEED FOR PERIOD = ',F12.2,'GRAMS'/)
180 CONTINUE
123 CONTINUE
STOP
END
```

APPENDIX III

List of BROCK Fish Culture Program

BROCK

```
WRITE(6,20)
20 FORMAT(3X,'TYPE IN THE POND LOADING FORMULA YOU WISH TO USE---TYPE
IN 1 FOR WILLOUGHBY; 2 FOR WESTERS; 3 FOR LIAO; 4 FOR PIPER DENSITY INDEX
METHOD; 5 FOR PIPER FLOW INDEX METHOD; and 6 FOR KLONTZ')
READ(5,*)LL
IF(LL.EQ.1) GO TO 126
IF(LL .EQ. 2) GO TO 71
IF(LL .EQ. 3) GO TO 157
IF(LL .EQ. 4) GO TO 43
IF(LL.EQ.5) GO TO 98
WRITE(6,21)
21 FORMAT(3X,'YOU HAVE CHOSEN THE KLONTZ LOADING FORMULA--TYPE IN THE
NUMBER OF PONDS TO BE LOADED--EXAMPLE ++? 5')
READ(5,*)NPL
DO 1 J-1,NPL
WRITE(6,22)
22 FORMAT(3X,'TYPE IN POND NUMBER AND HOW MANY DAYS THE PERIOD IS TO RUN----
EXAMPLE?  10,14')
READ(5,*)NP,ND
WRITE(6,23)
23 FORMAT(3X,'TYPE IN DELTA L, FISH LENGTH, K-FACTOR, ESTIMATED CONVERSION')
READ(5,*)DELTAL,ZLONG,ZKFACT,ESTCON
WRITE(6,24)
24 FORMAT(3X,'TYPE IN POND VOLUME,POND CHANGES/HOUR,PLI NUMBER,% DAILY MOR
TALITY.')
READ (5,*)VOL,RDELTA,PLI,PCMORT
WRITE(6,25)NP
25 FORMAT(20X,'KLONTZ LOADING METHOD FOR POND ',I2/)
WRITE(6,26)ZLONG,ZKFACT
26 FORMAT(3X,'STARTING FISH LENGTH = ',F7.4,T45,'K-FACTOR = ',F7.6/)
WRITE(6,27)DELTAL,ESTCON
27 FORMAT(3X,'DELTA L - 1,F6.4,T45,'ESTIMATED CONVERSION = ',F5.3/)
WRITE(6,28)VOL,PCMORT
28 FORMAT(3X,'POND VOLUME = ',F9.2,T45,'% DAILY MORTALITY = ',F5.3/)
WRITE(6,29)PLI,RDELTA
29 FORMAT(3X,'PLI NUMBER = ',F4.3,T45,'POND CHANGES/HOUR = ',F5.3/)
WRITE(6,30)
30 FORMAT(3X,'DAY  POND WT.  NO/LB  LENGTH  % BW FED   FEED  No. Fish'/)
ZLONG=ZLONG+DELTAL*(FLOAT(ND)-1.)
ZNOLB=1./(ZKFACT*ZLONG**3)
ZPLI=VOL*RDELTA*ZLONG*PLI
ZNUMB=ZPLI*ZNOLB/((1.-PCMORT/100.)**(FLOAT(ND)-1.))
ZLONG=ZLONG-DELTAL*(FLOAT(ND)-1.)
FEDSUM=0.
ZGPM=VOL*RDELTA*7.5/60.
CALL FISH(FEDSUM,ZKFACT,ZLONG,ZNUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM)
1 CONTINUE
GO TO 75
43 WRITE(6,31)
31 FORMAT(3X,'YOU HAVE CHOSEN THE PIPER DENSITY INDEX METHOD---TYPE IN
THE NUMBER OF PONDS TO BE LOADED---EXAMPLE ? 5')
READ(5,*)NPL
```

```
500 DO 2 J=1,NPL
510 WRITE (6,22)
520 READ(5,*)NP,ND
530 WRITE(6,23)
540 READ(5,*)DELTAL,ZLONG,ZKFACT,ESTCON
550 WRITE(6,32)
560 32 FORMAT(3X,'TYPE IN POND VOLUME,WATER TEMPERATURE, MAXIMUM DENSITY
INDEX, % DAILY MORTALITY,POND TURNOVERS/HR')
570 READ(5,*)VOL,TEMP,DI,PCMORT,RDELTA
580 WRITE(6,33)NP
590 33 FORMAT(20X,'PIPER DENSITY INDEX METHOD FOR POND ',I2/)
600 WRITE (6,26) ZLONG,ZKFACT
610 WRITE (6,27) DELTAL,ESTCON
620 WRITE (6,34) DI,TEMP
630 34 FORMAT(3X,'MAXIMUM DENSITY INDEX = ',F4.3,T45,'WATER TEMPERATURE =
',F3.0/)
640 WRITE (6,28) VOL,PCMORT
660 WRITE (6,30)
670 ZLONG=ZLONG+DELTAL*(FLOAT(ND)-1.)
680 ZMDI=ZLONG*VOL*DI
690 ZNOLB=1./(ZKFACT*ZLONG**3)
700 ZNUMB=ZMDI*ZNOLB/((1.-PCMORT/100.)**(FLOAT(ND)-1.)
710 ZLONG+ZLONG-DELTAL*(FLOAT(ND)-1.)
720 FEDSUM=0.
730 ZGPM=VOL*RDELTA*7.5/60.
740 CALL FISH (FEDSUM,ZKFACT,ZLONG,ZNUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM)
750 2 CONTINUE
760 GO TO 75
770 71 WRITE (6,99)
780 99 FORMAT(3X,'YOU HAVE CHOSEN THE WESTERS LOADING FORMULA---TYPE IN THE
NUMBER OF PONDS TO BE LOADED--EXAMPLE?  5')
790 READ (5,*)NPL
800 D) 3 J=1,NPL
810 WRITE (6,22)
830 READ (5,*)NP,ND
840 WRITE (6,23)
850 READ (5,*)DELTAL,ZLONG,ZKFACT,ESTCON
860 WRITE (6,35)
870 35 FORMAT(3X,'TYPE IN POND CHANGES/HOUR, POND VOLUME, MAXIMUM POUNDS OF FISH
/GPM, % DAILY MORTALITY.')
880 READ (5,*)RDELTA,VOL,WGPM,PCMORT
890 ZGPM=WGPM
900 WRITE (6,36)NP
910 36 FORMAT (20X,'WESTERS LOADING METHOD FOR POND ',I2/)
920 WRITE (6,26)ZLONG,ZKFACT
930 WRITE (6,27) DELTAL,ESTCON
940 WRITE (6,28) VOL ,PCMORT
950 WRITE (6,37)RDELTA,WGPM
960 37 FORMAT(3X,'POND CHANGES / HOUR = ',F5.3,T45,'LBS. FISH/GPM = ',5.2/)
980 WRITE (6,30)
990 ZLONG=ZLONG+DELTAL*(FLOAT(ND)-1.)
1000 ZNOLB=1./(ZKFACT*ZLONG**3)
1010 ZWEST=WGPM*RDELTA*VOL/8.
1020 ANUMB=ZWEST*ZNOLB/((1.-PCMORT/100.)**(FLOAT(ND(-1.))
```

```
1030 ZLONG=ZLONG-DELTAL*(FLOAT(ND)-1.)
1040 FEDSUM=0.
1050 CALL FISH (FEDSUM,ZKFACT,ALONG,ANUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM)
1060 3 CONTINUE
1070 GO TO 75
1080 98 WRITE (6,38)
1090 38 FORMAT(3X,'YOU HAVE CHOSEN THE PIPER FLOW INDEX METHOD----TYPE IN
THE NUMBER OF PONDS TO BE LOADED--EXAMPLE?  5')
1100 READ (5,*) NPL
1110 DO 4 J=1,NPL
1120 WRITE (6,22)
1130 READ (5,*) NP,ND
1140 WRITE (6,24)
1150 READ (5,*)DELTAL,ZLONG,ZKFACT,ESTCON
1160 WRITE (6,39)
1170 39 FORMAT(3X,'TYPE IN F-FACTOR, WATER TEMPERATURE, INFLOW (GPM), % DAILY
MORTALITY.')
1180 READ (5,*)ZFFACT,TEMP,ZGPM,PCMORT
1190 WRITE (6,40)NP
1200 40 FORMAT(17X,'PIPER FLOW INDEX METHOD FOR POND ',I2/)
1210 WRITE (6,26)ZLONG,ZKFACT
1220 WRITE (6,27)DELTAL,ESTCON
1230 WRITE (6,41)ZGPM,TEMP
1240 41 FORMAT(3X,'INFLOW (GPM) = ',F6.1,T45,'WATER TEMPERATURE = ',F3.0/)
1250 WRITE(6,732)ZFFACT,PCMORT
1260 732 FORMAT(3X,'F-FACTOR = ',F5.2,T45,'% DAILY MORTALITY = ',F5.3/)
1280 WRITE (6,30)
1290 ZLONG=ZLONG+DELTAL*(FLOAT(ND)-1.)
1300 ZNOLB=1./(ZKFACT*ZLONG**3)
1310 ZPF=ZFFACT*ZLONG*ZGPM
1320 ZNUMB=ZPF*ZNOLB/((1.-PCMORT/100.)**(FLOAT(ND)-1.))
1330 ZLONG=ZLONG-DELTAL*(FLOAT(ND)-1.))
1340 FEDSUM=0.
1350 CALL FISH (FEDSUM,ZKFACT,ZLONG,ANUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM)
1360 4 CONTINUE
1370 GO TO 75
1380 126 WRITE (6,42)
1390 42 FORMAT(3X,'YOU HAVE CHOSEN THE WILLOUGHBY POND LOADING METHOD---TYPE
IN THE NUMBER OF PONDS TO BE LOADED--EXAMPLE?  5')
1400 READ (5,*)
1410 DO 5 J-1,NPL
1420 WRITE (6,22)
1430 READ (5,*)NP,ND
1440 WRITE (6,23)
1450 READ (5,*) DELTAL,ZLONG,ZKFACT,ESTCON
1460 WRITE (6,430)
1470 430 FORMAT(3X,'TYPE IN OXYGEN AT INFLOW, OXYGEN AT OUTFALL, WATER
TEMPERATURE, INFLOW (GPM), % DAILY MORTALITY')
1480 READ (5,*)OIN,OOUT,TEMP,ZGPM,PCMORT
1490 WRITE (6,44)NP
1500 44 FORMAT(18X,'WILLOUGHBY LOADING METHOD FOR POND ',I2/)
1510 WRITE (6,26)ZLONG,ZKFACT
1520 WRITE (6,27)DELTAL,ESTCON
```

```
WRITE (6,45) OIN,OOUT
45 FORMAT(3X,'OXYGEN AT INFLOW = ',F4.1,T45,'OXYGEN AT OUTFALL = ',F4.1/)
WRITE(6,460)ZGPM,TEMP
460 FORMAT(3X,'INFLOW = ',F6.1,T45,'WATER TEMPERATURE = ',F3.0/)
WRITE (6,30)
ZLONG=ZLONG+DELTAL*(FLOAT(ND)-1.)
ZNOLB=1./(ZKFACT*ZLONG**3)
PWILL=(OIN-OOUT)*.0545*ZGPM
PCBDWT=ESTCON*300.*DELTAL/ZLONG
ZWILL-PWILL/(PCBDWT*.01)
ZNUMB=ZWILL*ZNOLB/((1.-PCMORT/100.)**(FLOAT(ND)-1.))
ZLONG=ZLONG-DELTAL*(FLOAT(ND)-1.)
FEDSUM =0.
CALL FISH (FEDSUM,ZKFACT,ZLONG,ZNUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM)
5 CONTINUE
GO TO 75
157 WRITE (6,46)
46 FORMAT (3X,'YOU HAVE CHOSEN THE LIAO METHOD --TYPE IN THE NUMBER OF
PONDS TO BE LOADED--EXAMPLE?  5')
READ (5,*)NPL
WRITE (6,47)
47 FORMAT(3X,'TYPE IN 1 FOR SALMON; 2 FOR TROUT.')
READ (5,*)SPECIE
DO 6 J=1,NPL
WRITE (6,22)
READ (5,*)NP,ND
WRITE (6,23)
READ (5,*)DELTAL,ZLONG,ZKFACT,ESTCON
WRITE (6,430)
READ (5,*)OIN,OOUT,TEMP,ZGPM,PCMORT
WRITE (6,48)NP
48 FORMAT(20X,'LIAO LOADING METHOD FOR POND ',I2/)
WRITE (6,26)ZLONG,ZKFACT
WRITE (6,27) DELTAL,ESTCON
WRITE (6,45) OIN,OOUT
WRITE(6,460)ZGPM,TEMP
WRITE (6,30)
ZLONG=ZLONG+DELTAL*(FLOAT(ND)-1.)
W=ZKFACT*ZLONG**3
ZNOLB=1./W
IF(SPECIE.EQ.1.) GO TO 189
ZM=-.138
IF (TEMP.GE.50.) GO TO 186
ZN=3.13
GO TO 196
186 ZK=.000305
ZN=1.855
GO TO 196
189 ZM=-.194
IF (TEMP.GE.50.) GO TO 194
ZK=7.2E-07
ZN=3.2
GO TO 196
194 ZK=.000049
```

```
ZN=2.12
196 ZLIAO=ZGPM*1.2*(OIN-OOUT)/(ZK*TEMP**ZN*W**ZM)
ZNUMB=ZLIAO*ZNOLB/((1.-PCMORT/100.)**(FLOAT(ND)-1.))
ZLONG=ZLONG-DELTAL*(FLOAT(ND)-1.)
FEDSUM = 0.
CALL FISH (FEDSUM,ZKFACT,ZLONG,ANUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM)
6 CONTINUE
75 CONTINUE
END
SUBROUTINE FISH (FEDSUM,ZKFACT,ZLONG,ZNUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM)
DO 15 I=1,ND
ZNOLB=1./(ZKFACT*ZLONG**3)
TOTWT-ZNUMB/ZNOLB
PCBDWT=ESTCON*300.*DELTAL/ZLONG
FOODFD=TOTWT*PCBDWT/100.
FEDSUM=FEDSUM+FOODFD
WRITE(6,750)*,TOTWT,ZNOLB,ZLONG,PCBDWT,FOODFD,ZNUMB
750 FORMAT(1X,*3,F10.2,F8.2,F7.2,F10.2,F8.1,F9.0/)
ZLONG=ZLONG+DELTAL
ZNUMB=ZNUMB-(ZNUMB*(PCMORT/100.))
15 CONTINUE
WRITE (6,76)FEDSUM
76 FORMAT(2X,'TOTAL FEED FOR PERIOD = ',F12.2,'POUNDS'/)
RETURN
END
```

APPENDIX IV

List of IRV Fish Culture Program

IRV

```
100 WRITE(6,20)
110 20 FORMAT(3X,'TYPE IN THE POND LOADING FORMULA YOU WISH TO USE---TYPE
IN 1 FOR WILLOUGHBY; 2 FOR WESTERS; 3 FOR LIAO; 4 FOR PIPER DENSITY INDEX
METHOD; 5 FOR PIPER FLOW INDEX METHOD; and 6 FOR KLONTZ')
120 READ(5,*)LL
130 IF(LL.EQ.1) GO TO 126
140 IF(LL .EQ. 2) GO TO 71
150 IF(LL .EQ. 3) GO TO 157
160 IF(LL .EQ. 4) GO TO 43
170 IF(LL.EQ.5) GO TO 98
180 WRITE(6,21)
190 21 FORMAT(3X,'YOU HAVE CHOSEN THE KLONTZ LOADING FORMULA--TYPE IN THE
NUMBER OF PONDS TO BE LOADED--EXAMPLE ++? 5')
200 READ(5,*)NPL
210 DO 1 J=1,NPL
220 WRITE(6,22)
230 22 FORMAT(3X,'TYPE IN POND NUMBER AND HOW MANY DAYS THE PERIOD IS TO
RUN---- EXAMPLE?  10,14')
240 READ(5,*)NP,ND
250 WRITE(6,23)
260 23 FORMAT(3X,'TYPE IN DELTA L, FISH LENGTH, K-FACTOR, ESTIMATED CONVERSION')
270 READ(5,*)DELTAL,ZLONG,ZKFACT,ESTCON
280 WRITE(6,24)
290 24 FORMAT(3X,'TYPE IN POND VOLUME,POND CHANGES/HOUR,PLI NUMBER,% DAILY
MORTALITY.')
300 READ (5,*)VOL,RDELTA,PLI,PCMORT
302 WRITE(6,240)
304 240 FORMAT(3X,'TYPE IN WATER TEMPERATURE AND PH')
306 READ(5,*)F,PH
310 WRITE(6,25)NP
320 25 FORMAT(20X,'KLONTZ LOADING METHOD FOR POND ',I2/)
330 WRITE(6,26)ZLONG,ZKFACT
340 26 FORMAT(3X,'STARTING FISH LENGTH = ',F6.4,T45,'K-FACTOR = ',F7.6/)
350 WRITE(6,27)DELTAL,ESTCON
360 27 FORMAT(3X,'DELTA L = ',F6.4,T45,'ESTIMATED CONVERSION = ',F5.3/)
370 WRITE(6,28)VOL,PCMORT
380 28 FORMAT(3X,'POND VOLUME = ',F9.2,T45,'% DAILY MORTALITY - ',F5.3/)
390 WRITE(6,29)PLI,RDELTA
400 29 FORMAT(3X,'PLI NUMBER = ',F4.3,T45,'POND CHANGES/HOUR = ',F5.3/)
410 WRITE(6,295)
420 295 FORMAT(T50,'LBS SOLIDS/',T68,'FREE')
430 WRITE(6,30)
440 30 FORMTA(2X,'DAY  POND WT.  NO/LB  LENGTH  % BW  FEED  FISH  100#FISH
NH3-N  NH3'/)
450 ZLONG=ZLONG+DELTAL*(FLOAT(ND)-1.)
460 ZNOLB=1./(ZKFACT*ZLONG**3)
470 ZPLI=VOL*RDELTA*ZLONG*PLI
480 ZNUMB-ZPLI*ZNOLB/((1.-PCMORT/100.)**(FLOAT(ND)-1.))
490 ZLONG=ZLONG-DELTAL*(FLOAT(ND)-1.)
500 FEDSUM=0.
510 ZGPM=VOL*RDELTA*7.5/60.
520 CALL FISH (FEDSUM,ZKFACT,ZLONG,ZNUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM,F,PH)
530 1 CONTINUE
540 GO TO 75
```

```
550 43 WRITE(6,31)
560 31 FORMAT(3X,'YOU HAVE CHOSEN THE PIPER DENSITY INDEX METHOD---TYPE
IN THE NUMBER TO BE LOADED---EXAMPLE ? 5')
580 READ(5,*)NPL
590 DO 2 J=1,NPL
600 WRITE (6,22)
610 READ(5,*)NP,ND
620 WRITE(6,23)
630 READ(5,*)DELTAL,ZLONG,ZKFACT,ESTCON
640 WRITE(6,32)
650 32 FORMAT(3X,'TYPE IN POND VOLUME,WATER TEMPERATURE,MAXIMUM DENSITY
INDEX, % DAILY MORTALITY,POND TURNOVERS/HR')
660 READ(5,*)VOL,TEMP,DI,PCMORT,RDELTA
662 WRITE(6,244)
664 READ(5,*)PH
670 WRITE(6,33)NP
680 33 FORMAT(20X,'PIPER DENSITY INDEX METHOD FOR POND ',I2/)
690 WRITE (6,26) ZLONG,ZKFACT
700 WRITE (6,27) DELTAL,ESTCON
710 WRITE (6,34) DI,TEMP
720 34 FORMAT(3X,'MAXIMUM DENSITY INDEX = ',F4.3,T45,'WATER TEMPERATURE =
',F3.0/)
730 WRITE (6,28) VOL,PCMORT
740 WRITE(6,295)
750 WRITE (6,30)
760 ZLONG=ZLONG+DELTAL*(FLOAT(ND)-1.)
770 ZMDI=ZLONG*VOL*DI
780 ZNOLB=1./(ZKFACT*ZLONG**3)
790 ZNUMB=ZMDI*ZNOLB/((1.-PCMORT/100.)**(FLOAT(ND)-1.))
800 ZLONG=ZLONG-DELTAL*(FLOAT(ND)-1.)
805 F=TEMP
810 FEDSUM=0.
820 ZGPM=VOL*RDELTA*7.5/60.
830 CALL FISH (FEDSUM,ZKFACT,ZLONG,ZNUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM,F,PH)
840 2 CONTINUE
850 GO TO 75
860 71 WRITE (6,99)
870 99 FORMAT(3X,'YOU HAVE CHOSEN THE WESTERS LOADING FORMULA---TYPE IN THE
NUMBER OF PONDS TO BE LOADED--EXAMPLE? 5')
880 READ (5,*)NPL
890 DO 3 J=1,NPL
900 WRITE (6,22)
920 READ (5,*)NP,ND
930 WRITE (6,23)
940 READ (5,*)DELTAL,ZLONG,ZKFACT,ESTCON
950 WRITE (6,35)
960 35 FORMAT(3X,'TYPE IN POND CHANGES/HOUR, POND VOLUME, MAXIMUM POUNDS OF
FISH/GPM, % DAILY MORTALITY.')
970 READ (5,*)RDELTA,VOL,WGPM,PCMORT
972 WRITE(6,250)
974 READ(5,*)F,PH
980 ZGPM=WGPM
990 WRITE (6,36)NP
```

```
1904 READ(5,*)PH
1906 F=TEMP
1910 WRITE (6,48(NP
1920 48 FORMAT(20X,'LIAO LOADING METHOD FOR POND ',I2/)
1930 WRITE (6,26)ZLONG,ZKFACT
1940 WRITE (6,27) DELTAL,ESTCON
1950 WRITE (6,45) OIN,OOUT
1960 WRITE(6,460)ZGPM,TEMP
1965 WRITE(6,295)
1970 WRITE (6,30)
1980 ZLONG=ZLONG+DELTAL*(FLOAT(ND)-1.)
1990 W=ZKFACT*ZLONG**3
2000 ZNOLB=1./W
2010 IF(SPECIE.EQ.1.) GO TO 189
2020 ZM=-.138
2030 IF (TEMP.GE.50.) GO TO 186
2040 ZK=.0000019
2050 ZN=3.13
2060 GO TO 196
2070 186 ZK=.000305
2080 ZN=1.855
2090 GO TO 196
2100 189 ZM=-.194
2110 IF (TEMP.GE.50.) GO TO 194
2120 ZK=7.2E-07
2130 ZN=3.2
2140 GO TO 196
2150 194 ZK=.000049
2160 ZN-2.12
2170 196 ZLIAO=ZGPM*1.2*(OIN-OOUT(/(ZK*TEMP**ZN*W**ZM)
2180 ZNUMB=ZLIAO*ZNOLB/((1.-PCMORT/100.)**(FLOAT(ND)-1.))
2190 ZLONG=ZLONG-DELTAL*(FLOAT(ND)-1.)
2200 FEDSUM = 0.
2210 CALL FISH (FEDSUM,ZKFACT,ZLONG,ZNUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM,F,PH)
2220 6 CONTINUE
2230 75 CONTINUE
2240 END
2250 SUBROUTINE FISH (FEDSUM,ZKFACT,ZLONG,ZNUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM,F,PH)
2260 DO 15 I=1,ND
2263 NTEMP=5*(F-3s.)/9.
2266 IF(NTEMP .LT. 4)NTEMP=4
2268 NNUM=NTEMP-4
2270 ZNOLB=1./(ZKFACT*ZLONG**3)
2272 IF(PH .LT. 6.5)PH=6.5)
2274 IF(PH .GT. 9.9)PH=9.0)
2276 AMONK=(NNUM*.0157+1.48)
2278 WATERK=(NNUM*.398+1.735)*10**(-5)
2279 QATERK=NNUM*.398+1.735
2280 TOTWT=ZNUMB/ZNOLB
2290 PCBDWT=ESTCON*300.*DELTAL/ZLONG
2300 FOODFD=TOTWT*PCBDWT/100.
2310 FEDSUM=FEDSUM+FOODFD
```

```
GO TO 75
126 WRITE (6,42)
42 FORMAT(3X,'YOU HAVE CHOSEN THE WILLOUGHBY POND LOADING METHOD---
TYPE IN THE NUMBER OF PONDS TO BE LOADED--EXAMPLE?  5')
READ (5,*)NPL
DO 5 J=1,NPL
WRITE (6,22)
READ (5,*)NP,ND
WRITE (6,23)
READ (5,*) DELTAL,ZLONG,ZKFACT,ESTCON
WRITE (6,430)
430 FORMAT(3X,'TYPE IN OXYGEN AT INFLOW, OXYGEN AT OUTFALL, WATER
TEMPERATURE, INFLOW (GPM), % DAILY MORTALITY')
READ (5,*)OIN,OOUT,TEMP,ZGPM,PCMORT
WRITE(6,244)
READ(5,*)PH
F=TEMP
WRITE (6,44)NP
44 FORMAT(18X,'WILLOUGHBY LOADING METHOD FOR POND ',I2/)
WRITE (6,26)ZLONG,ZKFACT
WRITE (6,27) DELTAL,ESTCON
WRITE (6,45) OIN,OOUT
45 FORMAT(3X,'OXYGEN AT INFLOW = ',F4.1,T45,'OXYGEN AT OUTFALL = ',F4.1/)
WRITE(6,460)ZGPM,TEMP
460 FORMAT(3X,'INFLOW = ',F6.1,T45,'WATER TEMPERATURE = ',F3.0/)
WRITE(6,295)
WRITE (6,30)
ZLONG=ZLONG+DELTAL*(FLOAT(ND)-1.)
ZNOLB=1./(ZKFACT*ZLONG**3)
PWILL=(OIN-OOUT)*.0545*ZGPM
PCBDWT=ESTCON*300.DELTAL/ZLONG
ZWILL=PWILL/(PCBDWT*.01)
ZNUMB-ZWILL*ZNOLB/((1.-PCMORT/100.)**(FLOAT(ND)-1.))
ZLONG=ZLONG-DELTAL*(FLOAT(ND)-1.)
FEDSUM =0.
CALL FISH (FEDSUM,ZKFACT,ZLONG,ZNUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM,F,PH)
5 CONTINUE
GO TO 75
157 WRITE (6,46)
46 FORMAT (3X,'YOU HAVE CHOSEN THE LIAO METHOD --TYPE IN THE NUMBER OF
PONDS TO BE LOADED--EXAMPLE?  5')
READ (5,*)NPL
WRITE (6,47)
47 FORMAT(3X,'TYPE IN 1 FOR SALMON; 2 FOR TROUT.')
READ (5,*)SPECIE
DO 6 J=1,NPL
WRITE (6,22)
READ (5,*)NP,ND
WRITE (6,23)
READ (5,*)DELTAL,ZLONG,ZKFACT,ESTCON
WRITE (6,430)
READ (5,*)OIN,OOUT,TEMP,ZGPM,PCMORT
WRITE (6,244)
```

```
1000 36 FORMAT (20X,'WESTERS LOADING METHOD FOR POND ',I2/)
1010 WRITE (6,26)ZLONG,ZKFACT
1020 WRITE (6,27) DELTAL,ESTCON
1030 WRITE (6,28) VOL , PCMORT
1040 WRITE (6,37)RDELTA,WGPM
1050 37 FORMAT(3X,'POND CHANGES / HOUR - ',F5.3,T45,'LBS. FISH/GPM - ',F5.2/)
1060 WRITE(6,295)
1070 WRITE (6,30)
1080 ZLONG=ZLONG+DELTAL*(FLOAT(ND)-1.)
1090 ZNOLB=1./(ZKFACT*ZLONG**3)
1100 ZWEST=WGPM*RDELTA*VOL/8.
1110 ZNUMB=ZWEST*ZNOLB/((1.-PCMORT/100.)**(FLOAT(ND)-1.))
1120 ZLONG=ZLONG-DELTAL*(FLOAT(ND)-1.)
1125 ZGPM=VOL*RDELTA*7.5/60.
1130 FEDSUM=0.
1140 CALL FISH (FEDSUM,ZKFACT,ZLONG,ZNUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM,F,PH)
1150 3 CONTINUE
1160 GO TO 75
1170 98 WRITE (6,38)
1180 38 FORMAT(3X,'YOU HAVE CHOSEN THE PIPER FLOW INDEX METHOD----TYPE IN
THE NUMBER OF PONDS TO BE LOADED--EXAMPLE?  5')
1190 READ (5,*) NPL
1200 DO 4 J=1,NPL
1210 WRITE (6,22)
1220 READ (5,*) NP,ND
1230 WRITE (6,23)
1240 READ (5,*)DELTAL,ZLONG,ZKFACT,ESTCON
1250 WRITE (6,39)
1260 39 FORMAT(3X,'TYPE IN F-FACTOR, WATER TEMPERATURE, INFLOW (GPM), % DAILY
MORTALITY.')
1270 READ (5,*)ZFFACT,TEMP,ZGPM,PCMORT
1272 WRITE(6,244)
1274 244 FORMAT(3X,'TYPE IN PH OF WATER')
1276 READ(5,*)PH
1278 F=TEMP
1280 WRITE (6,40)NP
1290 40 FORMAT(17X,'PIPER FLOW INDEX METHOD FOR POND ',I2/)
1300 WRITE (6,26)ZLONG,ZKFACT
1310 WRITE (6,27)DELTAL,ESTCON
1320 WRITE (6,41)ZGPM,TEMP
1330 41 FORMAT(3X,'INFLOW (GPM) = ',F6.1,T45,'WATER TEMPERATURE = ',F3.0/)
1340 WRITE(6,732)ZFFACT,PCMORT
1350 732 FORMAT(3X,'F-FACTOR = ',F5.2,T45,'% DAILY MORTALITY = ',F5.3/)
1360 WRITE(6,295)
1370 WRITE (6,30)
1380 ZLONG=ZLONG+DELTAL*(FLOAT(ND)-1.)
1390 ZNOLB=1./(ZKFACT*ZLONG**3)
1400 ZPF=ZFFACT*ZLONG*ZGPM
1410 ZNUMB=ZPF*ZNOLB/((1.-PCMORT/100.)**(FLOAT(ND)-1.))
1420 ZLONG=ZLONG-DELTAL*(FLOAT(ND)-1.)
1430 FEDSUM =0.
1440 CALL FISH (FEDSUM,ZKFACT,ZLONG,ZNUMB,ESTCON,DELTAL,PCMORT,ND,ZGPM,F,PH)
1450 4 CONTINUE
```

```
2320 SOLIDS=.95*FOODFD*(1-1/ESTCON)
2330 SLD=(SOLIDS/TOTWT)*100.
2340 WLSLDS=SOLIDS/(.012*ZGPM)
2350 AMONYA=.032*FOODFD
2360 WILAMO=AMONYA/(.012*ZGPM)
2366 PPH=PH-5.
2368 SUB1=(10**(-PPH))*1000
2370 SUB2=WATERK/SUB1
2372 SUB3=SUB2/AMONK
2374 AMOPCT=SUB3*.77
2378 AMONH3=AMOPCT*WILAMO/100.
2380 WRITE(6,750)I,TOTWT,ZNOLB,ZLONG,PCBDWT,FOODFD,ZNUMB,SLD,WILAMO,AMONH3
2390 750 FORMAT(1X,I3,F10.1,F8.2,F7.3,F7.2,F7.1,F8.0,2F7.3,F8.5/)
2400 ZLONG=ZLONG+DELTAL
2410 ZNUMB=ZNUMB-(ZNUMB*(PCMORT.100.))
2420 15 CONTINUE
2430 WRITE (6,76)FEDSUM
2440 76 FORMAT(2X,'TOTAL FEED FOR PERIOD = ',F12.2,'POUNDS'/)
2450 RETURN
2460 END
```

APPENDIX V

Computer Output Specimen Using the OWRT Program.

ROOM NUMBER 2A TANK NUMBER 1

DELTA L = 0.0350

TEMPERATURE = 59.

EST. CONVERSION = 1.500

POND CHANGES/HOUR = 2.500

STARTING FISH LENGTH = 3.0000

#/LB = 101.00

POND VOLUME = 3.690

DENSITY INDEX = 0.500

K-FACTOR = 0.000410

% DAILY MORTALITY = 0.030

DAY	POND WEIGHT	NO./LB	LENGTH	% BW FED	FEED	NO. FISH
1	4.19	90.33	3.00	5.25	106.48	378.
2	4.34	87.25	3.03	5.19	108.82	378.
3	4.49	84.29	3.07	5.13	111.19	378.
4	4.64	81.48	3.10	5.07	113.59	378.
5	4.80	78.78	3.14	5.02	116.01	378.
6	4.97	76.21	3.17	4.96	118.47	378.
7	5.13	73.74	3.21	4.91	120.95	378.
8	5.30	71.38	3.24	4.85	129.15	378.
9	5.48	69.12	3.28	4.80	151.68	378.
10	4.64	66.95	3.31	4.75	134.24	378.
11	4.83	64.88	3.35	4.70	136.83	378.
12	6.02	62.88	3.38	4.65	139.45	378.
13	6.21	60.97	3.42	4.61	142.09	378.
14	6.40	59.14	3.45	4.56	0.0	378.

TOTAL FEED FOR PERIOD = 1603.95 GRAMS

APPENDIX VI

Computer Output Specimens Using the IRV Program

Input Data:

Fish - Rainbow trout

Length - 2.67 inches

Density factor - 0.4

ΔL - 0.03 inches/day

K-factor - 4.1×10^{-4}

Daily mortality (est.) - 0.03%

Water - temperature - $59^{o}F$

Inflow - 775 gpm (1.72 cfs)

Water replacement time - 28.5 min

Elevation - 1000 ft above MSL

Dissolved oxygen (in) - 9.6 mg/l

Dissolved oxygen (out) - 6.0 mg/l

pH - 8.0

Pond volume - 3000 cu ft

Feed conversion (est.) - 1.6

WILLOUGHBY LOADING METHOD FOR POND 1

STARTING FISH LENGTH = 2.6700 K-FACTOR = .000400

DELTA L = 0.0300 ESTIMATED CONVERSION = 1.600

OXYGEN AT INFLOW = 9.6 OXYGEN AT OUTFALL = 6.0

INFLOW = 775.0 WATER TEMPERATURE = 59.

DAY	POND WT.	NO/LB	LENGTH	% BW	FEED	FISH	LBS SOLIDS/ 100#FISH	NH3-N	FREE NH3
1	2154.9	131.34	2.670	5.39	116.2	283028.	1.921	0.400	0.00361
2	2227.7	127.01	2.700	5.33	118.8	282943.	1.900	0.409	0.00369
3	2302.1	122.87	2.730	5.27	121.4	282858.	1.879	0.418	0.00377
4	2378.1	118.91	2.760	5.22	124.1	282773.	1.859	0.427	0.00385
5	2455.7	115.11	2.790	5.16	126.7	282689.	1.839	0.436	0.00394
6	2535.0	111.48	2.820	5.11	129.4	282604.	1.819	0.445	0.00402
7	2616.0	108.00	2.850	5.05	132.2	282519.	1.800	0.455	0.00411
8	2698.7	104.66	2.880	5.00	134.9	282434.	1.781	0.464	0.00419
9	2783.1	101.45	2.910	4.95	137.7	282349.	1.763	0.474	0.00428
10	2869.2	98.38	2.940	4.90	140.5	282265.	1.745	0.484	0.00436
11	2957.0	95.43	2.970	4.85	143.4	282180.	1.727	0.493	0.00445
12	3046.6	92.59	3.000	4.80	146.2	282095.	1.710	0.503	0.00454
13	3138.0	89.87	3.030	4.75	149.1	282011.	1.693	0.513	0.00463
14	3231.2	87.25	3.060	4.71	152.1	281926.	1.676	0.523	0.00472

TOTAL FEED FOR PERIOD = 1872.88 POUNDS

WESTERS LOADING METHOD FOR POND 1

STARTING FISH LENGTH = 2.6700

K-FACTOR = .000410

DELTA L = 0.0300

ESTIMATED CONVERSION = 1.600

POND VOLUME = 3000.00

% DAILY MORTALITY = 0.030

POND CHANGES/HOUR = 2.100

LBS. FISH/GPM = 4.28

DAY	POND WT.	NO/LB	LENGTH	% BW	FEED	FISH	LBS SOLIDS/ 100#FISH	NH3-N	FREE NH3
1	2247.8	128.14	2.670	5.39	121.2	288032.	1.921	0.411	0.01169
2	2323.7	123.92	2.700	5.33	123.9	287945.	1.900	0.420	0.01196
3	2401.3	119.88	2.730	5.27	126.7	287859.	1.879	0.429	0.01222
4	2480.6	116.01	2.760	5.22	129.4	287773.	1.859	0.438	0.01248
5	2561.6	112.31	2.790	5.16	132.2	287686.	1.839	0.448	0.01275
6	2644.3	108.76	2.820	5.11	135.0	287600.	1.819	0.457	0.01302
7	2728.8	105.36	2.850	5.05	137.9	287514.	1.800	0.467	0.01330
8	2815.1	102.10	2.880	5.00	140.8	287427.	1.781	0.477	0.01357
9	2903.1	98.98	2.910	4.95	143.7	287341.	1.763	0.486	0.01385
10	2992.9	95.98	2.940	4.90	146.6	287255.	1.745	0.496	0.01414
11	3084.5	93.10	2.970	4.85	149.6	287169.	1.727	0.506	0.01442
12	3178.0	90.33	3.000	4.80	152.5	287082.	1.710	0.517	0.01471
13	3273.3	87.68	3.030	4.75	155.6	286996.	1.693	0.527	0.01500
14	3370.5	85.12	3.060	4.71	158.6	286910.	1.676	0.537	0.01530

TOTAL FEED FOR PERIOD = 1953.64 POUNDS

LIAO LOADING METHOD FOR POND 1

STARTING FISH LENGTH = 2.6700

K-FACTOR = .000410

DELTA L = 0.0300

ESTIMATED CONVERSION = 1.600

OXYGEN AT INFLOW = 9.6

OXYGEN AT OUTFALL = 6.0

INFLOW = 775.0

WATER TEMPERATURE = 59.

DAY	POND WT.	NO/LB	LENGTH	% BW	FEED	FISH	LBS SOLIDS/ 100#FISH	NH3-N	FREE NH3
1	2057.2	123.14	2.670	5.39	110.9	263606.	1.921	0.382	0.00345
2	2126.7	123.92	2.700	5.33	113.4	263527.	1.900	0.390	0.00352
3	2197.7	119.88	2.730	5.27	115.9	263448.	1.879	0.399	0.00360
4	2270.3	116.01	2.760	5.22	118.4	263369.	1.859	0.408	0.00368
5	2344.4	112.31	2.790	5.16	121.0	263290.	1.839	0.416	0.00376
6	2420.1	108.76	2.820	5.11	123.6	263211.	1.819	0.425	0.00384
7	2497.4	105.36	2.850	5.05	126.2	263132.	1.800	0.434	0.00392
8	2576.3	102.10	2.880	5.00	128.8	263053.	1.781	0.443	0.00400
9	2646.9	98.98	2.190	4.95	131.5	262974.	1.763	0.452	0.00408
10	2739.1	95.98	2.940	4.90	134.2	262895.	1.745	0.462	0.00417
11	2822.9	93.10	2.970	4.85	136.9	262816.	1.727	0.471	0.00425
12	2908.5	90.33	3.000	4.80	139.6	262737.	1.710	0.480	0.00434
13	2995.7	87.68	3.030	4.75	142.4	262658.	1.693	0.490	0.00442
14	3084.7	85.12	3.060	4.71	145.2	262579.	1.676	0.499	0.00451

TOTAL FEED FOR PERIOD = 1787.97 POUNDS

PIPER DENSITY INDEX METHOD FOR POND 1

STARTING FISH LENGTH = 2.6700 | K-FACTOR = .000410

DELTA L = 0.0300 | ESTIMATED CONVERSION = 1.600

MAXIMUM DENSITY INDEX = .400 | WATER TEMPERATURE = 59.

POND VOLUME = 3000.00 | % DAILY MORTALITY = 0.030

DAY	POND WT.	NO/LB	LENGTH	% BW	FEED	FISH	LBS SOLIDS/ 100#FISH	NH3-N	FREE NH3
1	2448.9	128.14	2.670	5.39	132.1	313797.	1.921	0.447	0.00404
2	2531.6	123.92	2.700	5.33	135.0	313703.	1.900	0.457	0.00413
3	2616.1	119.88	2.730	5.27	138.0	313608.	1.879	0.467	0.00422
4	2702.5	116.01	2.760	5.22	141.0	313514.	1.859	0.477	0.00431
5	2790.8	112.31	2.790	5.16	144.0	313420.	1.839	0.488	0.00440
6	2880.9	108.76	2.820	4.11	147.1	323326.	1.819	0.498	0.00450
7	2972.9	105.36	2.850	5.05	150.2	313232.	1.800	0.509	0.00459
8	3066.9	102.10	2.830	5.00	153.3	313138.	1.781	0.519	0.00469
9	3162.8	98.98	2.910	4.95	156.5	313044.	1.763	0.530	0.00478
10	3260.6	95.98	2.940	4.90	159.7	312950.	1.745	0.541	0.00488
11	3360.4	93.10	2.970	4.85	162.9	312856.	1.727	0.552	0.00498
12	3462.3	90.33	3.000	4.80	166.2	312762.	1.710	0.563	0.00508
13	3566.1	87.68	3.030	4.75	169.5	312669.	1.693	0.574	0.00518
14	3672.0	85.12	3.060	4.71	172.8	312575.	1.676	0.585	0.00528

TOTAL FEED FOR PERIOD = 2128.40 POUNDS

PIPER FLOW INDEX METHOD FOR POND 1

STARTING FISH LENGTH = 2.6700

K-FACTOR = .000410

DELTA L = 0.0300

ESTIMATED CONVERSION = 1.600

OXYGEN AT INFLOW = 775.0

WATER TEMPERATURE = 59.

INFLOW = 1.32

% DAILY MORTALITY = 0.030

DAY	POND WT.	NO/LB	LENGTH	% BW	FEED	FISH	LBS SOLIDS/ 100#FISH	NH3-N	FREE NH3
1	2087.7	128.14	2.670	5.39	112.6	267512.	1.921	0.387	0.00350
2	2158.2	124.92	2.700	5.33	115.1	267432.	1.900	0.396	0.00358
3	2230.2	119.88	2.730	5.27	117.6	267351.	1.869	0.405	0.00365
4	2303.9	116.01	2.760	5.22	120.2	267271.	1.859	0.414	0.00373
5	2379.1	112.31	2.790	5.16	122.8	267191.	1.839	0.423	0.00381
6	2456.0	108.76	2.820	5.11	125.4	267111.	1.819	0.432	0.00390
7	2534.4	105.26	2.850	5.05	128.1	267030.	1.800	0.441	0.00398
8	2614.5	102.10	2.880	5.00	130.7	267950.	1.781	0.450	0.00406
9	2696.3	98.98	2.910	4.95	133.4	266870.	1.763	0.459	0.00414
10	2779.7	95.98	2.940	4.90	136.1	266790.	1.745	0.468	0.00423
11	2864.8	93.10	2.970	4.85	138.9	266710.	1.727	0.478	0.00431
12	2951.6	90.33	3.000	4.80	141.7	266630.	1.719	0.487	0.00440
13	3040.1	87.68	3.030	4.75	144.5	266550.	1.693	0.497	0.00449
14	3130.4	85.12	3.060	4.71	147.3	266470.	1.676	0.507	0.00458

TOTAL FEED FOR PERIOD = 1814.46 POUNDS

KLONTZ LOADING METHOD FOR POND 1

STARTING FISH LENGTH = 2.6700		K-FACTOR = .000410	
DELTA L = 0.0300		ESTIMATED CONVERSION = 1.600	
POND VOLUME = 3000.00		% DAILY MORTALITY = 0.030	
PLI NUMBER = .165		POND CHANGES/HOUR =2.100	

DAY	POND WT.	NO/LB	LENGTH	% BW	FEED	FISH	LBS SOLIDS/ 100#FISH	NH3-N	FREE NH3
1	2121.3	123.14	2.670	5.39	114.4	271827.	1.921	0.387	0.00110
2	2193.0	123.92	2.700	5.33	117.0	271745.	1.900	0.396	0.00113
3	2266.2	119.88	3.730	5.27	119.5	271663.	1.879	0.405	0.00115
4	2341.1	116.01	2.760	5.22	122.1	271582.	1.859	0.414	0.00118
5	2417.5	112.31	2.790	5.16	124.8	271500.	1.839	0.423	0.00120
6	2495.6	108.76	2.820	5.11	127.4	271419.	1.819	0.432	0.00123
7	2575.3	105.36	2.850	5.05	130.1	271338.	1.800	0.441	0.00125
8	2656.7	102.10	2.880	5.00	132.8	271256.	1.781	0.450	0.00128
9	2739.7	98.98	2.910	4.95	135.6	271175.	1.763	0.459	0.00131
10	2824.5	95.98	2.940	4.90	138.3	271093.	1.745	0.468	0.00133
11	2911.0	93.10	2.970	4.85	141.1	271012.	1.727	0.478	0.00136
12	2999.2	90.33	3.000	4.80	144.0	270931.	1.710	0.487	0.00139
13	3089.1	87.68	3.030	4.75	146.8	270849.	1.693	0.497	0.00142
14	3180.9	85.12	3.060	4.71	149.7	270768.	1.676	0.507	0.00144

TOTAL FEED FOR PERIOD = 1843.72 POUNDS